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JANUARY 1918

BALTIMORE & OHIO COAL LOADING PIER

Showing Trimmer Conveyor Belt, Traveling Tower, and Loading Boom

(See page 15)

SOME DEVELOPMENTS IN THE ELECTRICAL INDUSTRY DURING 1917

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GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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GENERAL ELECTRIC REVIEW

A REVIEW OF THE INDUSTRY DURING 1917

The leading article in this issue is a summary of the progress in the electrical industry during the past year. To those who must keep abreast of the times, despite their specialized and intensive daily work, this article is recommended for careful reading.

The electrical industry has loyally responded to the European War demands for increased production. The exigency of the situation has resulted in an intensified production of apparatus which is confined mainly to classes of machines which had previously been standardized. Consequently, during the past year, less engineering effort could be concentrated upon research investigation and the production of new types of apparatus. In spite of this situation, however, there have been a considerable number of new developments, the more important of which are described with such brevity that "he who runs may read." While few exceptionally large electrical units were produced, there is shown a rate of developmental progress that does not suffer by comparison with the record of previous years.

The employment of women in many processes of electric manufacturing is not new, but the recent continually augmenting demands for apparatus hitherto produced exclusively by the labor of men, combined with the lessening of the normal masculine labor supply due to volunteering and selective conscription, necessitated a resort to the services of women operatives on a scale and for classes of work never before contemplated. The results have in general been highly satisfactory.

This article is therefore of timely interest in a double sense, for it records the economic effects of the great War upon one of America's greatest industries, as well as the scientific and engineering achievements in the eventful year of 1917.

MAKING SKILLED MECHANICS

To take boys of sixteen with only a grammar school education and make them into skilled mechanics in four years is the function of the apprenticeship system of the General Electric Company as described in this issue.

We invite the attention of our readers to this apprentice work, as it deals with one of the problems confronting American industry, especially during these war times. The creation of skilled workmen from school-boy raw material has its patriotic features: 102 graduates of this apprentice course are now in government positions, mostly in arsenals and navy yards, turning out munitions and accurate scientific instruments which will conserve lives in the army and navy.

In order to provide adequate facilities, such as modern machine tools and school-room and laboratory equipment, for the thorough training of the apprentices, the greater part of a million dollars has been spent; and during the four years that the boys are serving their apprentice course they are paid from $2100 to $3200. Therefore, for those boys who are unable to go to college these apprentice courses are obviously a happy combination of industry and instruction.

Statistics are included showing the earnings and positions held by many of the apprentice graduates, and the author points out that, in all probability, the trade which these boys learn will not become obsolete for many generations.

Mr. Thomas A. Edison has said: "We have laid good foundations for industrial prosperity. Now we want to assure the happiness and growth of the workers through vocational guidance and wisely managed employment departments. A great field for industrial experimentation and statesmanship is opening up."

Some Developments in the Electrical Industry During 1917

By John Liston

Publication Bureau, General Electric Company

This article constitutes our annual review of the activities of the electrical industry during the past year. Its scope, of course, increases with the growth of the industry, and while there is more to record on this occasion than on any previous one, there are yet many important developments of the year associated with war work that cannot be mentioned at this time for obvious reasons. Nevertheless, the advances in the industry that are outlined by Mr. Liston are unusual, and will be read with interest by all engineers.
—Editor.

When, in the fullness of time, the complete story of the developments in the electrical industry for 1917 is told, it will constitute a record of which the entire electrical fraternity may well be proud; but, at present, for reasons which will be appreciated by every American engineer, many items of interest must of necessity be omitted from any review covering the accomplishments of the industry.

Despite this limitation there remains for analysis in this article an impressive array of improvements secured in many classes of apparatus, and, as well, a number of new appliances and applications of apparatus previously developed which can be classed as distinctly new.

The feature of overshadowing importance, however, was the enormous increase in the volume of production of standard apparatus to meet unprecedented demands for power station, railway, and industrial equipment. For certain types of apparatus which had long been in general use, this increase actually represented advances of several hundreds of per cent as compared with the maximum output of preceding years. In response to emergency demands, numerous machines of large capacity were manufactured with a rapidity which had never before been attempted.

While there were many notable additions to the existing equipment of electric railroads, hydro-electric stations, and the power and lighting systems of a great variety of industries, as well as extension of electric service into new fields, there were comparatively few instances in which the unit capacity of the apparatus supplied exceeded the maximum ratings previously established.

In view of the number and variety of subjects covered in this article and the limitations imposed by the space available, complete

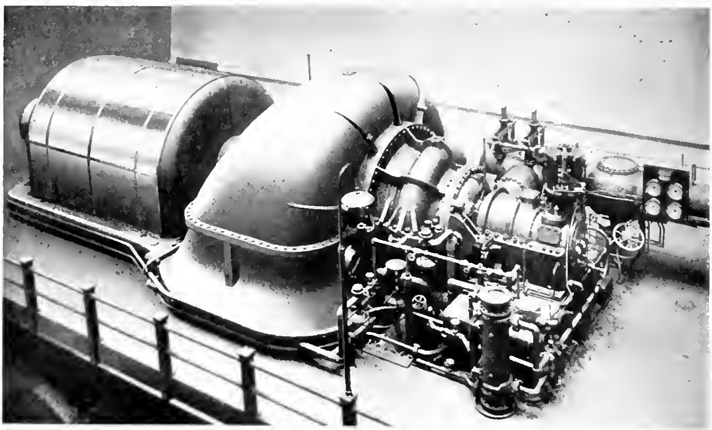


Fig. 1. 35,000-kw. Curtis Steam Turbo-generator Installed in Power Station of the Boston Elevated Co.

descriptive details cannot be given, and many items which would be of interest from an engineering standpoint have of necessity been omitted. The apparatus referred to, unless otherwise specified, is in every instance a product of the General Electric Company; but this does not invalidate the essential value of the cumulative effect of these references as a broad indication of the important tendencies in design, construction, and application throughout the manufacturing industry during the past year.

TURBINES

The pressing demands for turbines of all capacities necessitated the concentration of all efforts on the production of types of machines which were already developed and the postponement of development work which otherwise might have been undertaken.

A number of the large turbine-generator sets referred to in last year's review* by the author were shipped and are in operation. These sets consist in every case of a single turbine of single flow design connected to a single generator (see Figs. 1 and 2); and, in accordance with G-E turbine practice, they are designed to utilize efficiently the highest degrees of vacuum. It has often been pointed out that the volume of each pound of steam is almost twice as great at 29 inches as at 28 inches vacuum.

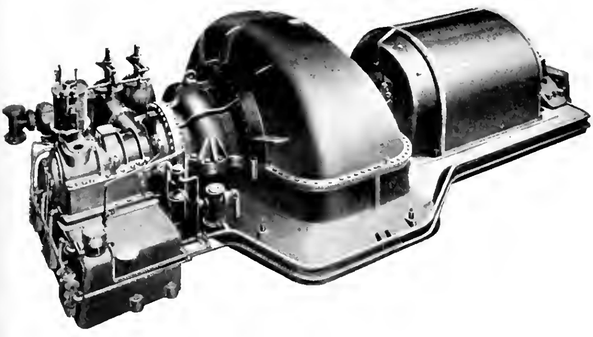


Fig. 2. 30,000-kw. 1800-r.p.m., 60-cycle Curtis Steam Turbo-generator

Geared turbine generator sets and geared sets for ship propulsion mentioned last year as new developments, have added another successful year to their record.

ALTERNATING CURRENT MACHINES

There were no changes of importance in the design or maximum rating of this class of apparatus, but there was an exceptional expansion in the production of standard machines.

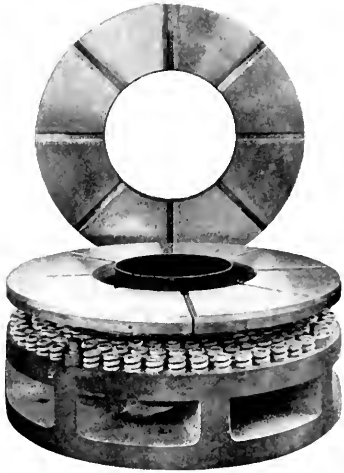


Fig. 3. Spring Supported Thrust-bearing Showing Rubbing Surface of Rotating Ring, Stationary Ring is Raised to Show Arrangement of Springs

The largest unit constructed was a horizontal shaft waterwheel driven generator rated at 20,000 kv-a., 6600 volts, 60 cycles, and operated at 360 r.p.m., or more than twice the speed of machines of the same class and kilowatt capacity previously built.

In low-speed machines there were two 10,000 kv-a., 6600-volt, 60-cycle vertical shaft waterwheel driven units operating at 55.6 r.p.m. These were supplied to the Cedar Rapids Mfg. and Power Co. of Quebec, and were similar to ten units previously installed by that company. They still represent the maximum of capacity development for machines of their class.

The spring-supported thrust bearing (Fig. 3) was developed by the General Electric Company to overcome certain difficulties

* General Electric Review, January, 1917.

experienced with other types of thrust bearings for vertical shaft generators. Of the many types in the market there was no other which automatically adjusted itself to unequal loading due to inaccuracies in workmanship or in alignment. While some other types may

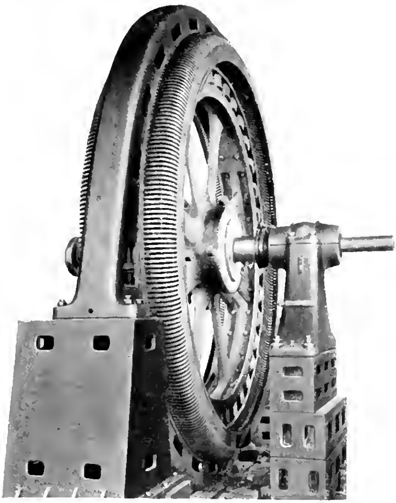


Fig. 4. 6250-kv-a., 6600-volt, 88-r.p.m. Generator for Gas Engine Drive

be properly adjusted when installed, a distinctive feature of the spring-supported bearing is that it will automatically adjust itself while in operation if there is a loss of alignment due to a settling of the foundation or to other causes.

So successful have these bearings proved in actual service that their use on G-E vertical shaft generators has been standardized.

The demand for generators for foreign water power developments was more than double that of any previous year and amounted to more than thirty 50-cycle, 6600-volt horizontal shaft alternators with rated outputs of from 2500 to 10,000 kv-a. Except for the unusual frequency, these machines were built in accordance with American standards.

Four alternators (Fig. 4), rated at 6250 kv-a., 6600 volts, 25 cycles, 88 r.p.m., were supplied for gas engine drive to the Bethlehem Steel Company, thereby carrying the maximum capacity for gas engine generator sets well beyond any previous rating.

The use of synchronous motors for direct compressor drive increased about 35 per cent above the requirements of previous years, and the motors supplied for this particular application aggregated about 65,000 h.p., with individual ratings ranging from 150 h.p. to 1020 h.p.

AUTOMATIC HYDRO-ELECTRIC GENERATING STATION

A hydro-electric plant equipped with three vertical shaft 500-kw., 2-phase, 60-cycle, 2300-volt, 60-r.p.m. generators, designed to operate in parallel with the steam power station of the Iowa Railway and Light Company at Cedar Rapids, Iowa, *represents the first application of automatic control on any commercial scale for this class of service.

The water power development is located about half a mile from the steam plant, and by means of float switches, actuated by the change in water level in the forebay, the generators are thrown in or cut out of service at any predetermined water stage. Remote control from the steam station is also provided.

Fig. 5. Magnet Frame of RF Motor Showing Construction and Arrangement of Pole Pieces

This system insures the most effective and economical use of the available water supply, and also permits the conservation of a sufficient supply of stored water, by suitable adjustment of the float switches, to utilize the capacity of the hydraulic plant during

* See article by L. B. Bonnett, in GENERAL ELECTRIC REVIEW, December 1917.

peak load demands on the steam power plant.

No operator is required for the hydroelectric station and the attendance is limited to periodic visits of inspection.

DIRECT-CURRENT MOTORS

The most important development of recent years, in direct-current motor design, was embodied in a complete new line of adjustable speed motors ranging from 2 h.p. to 125 h.p. in capacity.

By reference to Figs. 5 and 6 it will be seen that this new motor, which is known as Type RF, is provided with a distributed compensating winding embedded in slots in the main pole pieces, in addition to the commutating pole winding which had been previously accepted as the best practicable method of minimizing commutation troubles.

The use of this compensating winding practically prevents losses due to flux distortion, which, in previous commutating pole types, ran as high as 10 per cent, and the motor may be safely accelerated from low speed to high speed when connected to a friction load by inserting the total field resistance in one step.

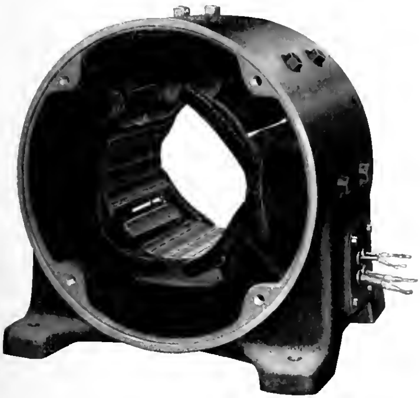


Fig. 6. Magnet Frame of RF Motor Showing Location and Arrangement of Coils

For ordinary operating conditions only a simple drum type controller is required, while for automatic service magnetic control of a very much simpler type than that necessary for the conventional commutating pole type of motor can be employed without sacrificing excellence of commutation.

ELECTRIC TRACTION

On account of the abnormal conditions due to the entrance of this country into the World War, the activities of the various large railroads looking to the electrification of heavy traffic and mountain grade sections were in most cases put aside pending the return of normal conditions. Railroads now operating electrical sections, however, placed orders for additional equipment and continue to add to their facilities as the traffic requirements dictate.

New York Central Railroad—Electric Division

During the year the New York Central Railroad placed in service ten additional 125-ton electric locomotives, which are duplicates of those furnished in 1914. These locomotives are of the high-speed passenger type, each equipped with eight bipolar gearless motors capable of handling trains between New York City and Albany in case the electrification should be extended.

Both the original type four-motor locomotives and the later eight-motor type (Fig. 7) continue to show remarkably low figures on locomotive maintenance, approximating since the beginning of service about 3½ cents per locomotive mile. This maintenance figure is probably not approached by any other electric locomotives of similar size now in service.

The suburban service on the electric division of the New York Central handled by multiple unit trains was augmented by eighteen motor-cars, each equipped with two GE-260 motors and Type "PC" control. This makes a total of forty multiple unit cars now using "PC" control on this system.

Canadian Northern Railway

During the early part of the year the Canadian Northern Railway placed in service on its Montreal terminal five of the six 83-ton, 2400-volt electric locomotives (Fig. 8) purchased for this electrification. While these locomotives have not been used to haul regular passenger and freight trains, they are in actual service hauling construction trains between the site of the new station and Cartierville, ten miles from the terminal, through the Mt. Royal Tunnel.

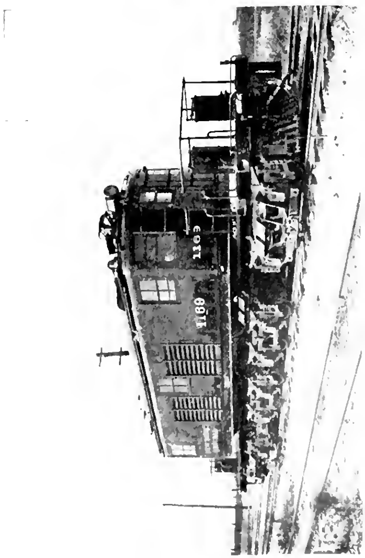


Fig. 7. Latest Type of Eight-motor New York Central Locomotive

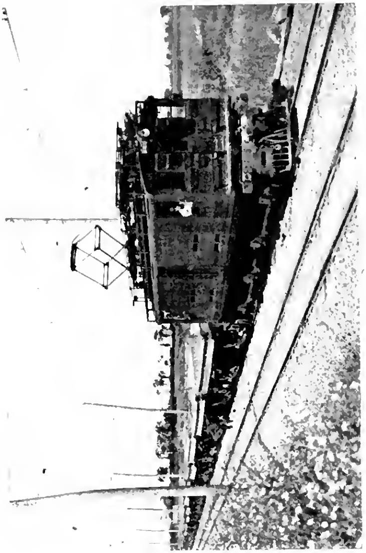


Fig. 8. 83-ton, 2400-volt, D-C. Locomotive Hauling Construction Train, Canadian Northern Terminal, Montreal, Canada

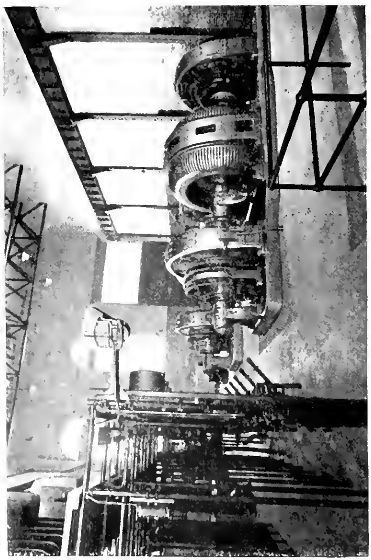


Fig. 9. Two 1500-kw., 2400-volt D-C. Motor-generator Sets in Montreal Sub-station, Canadian Northern Railway

Fig. 10. Chicago, Milwaukee, & St. Paul Switching Locomotive

The substation, located at the portal of the 3-mile tunnel under Mt. Royal, was entirely completed, and contains two 3-unit, 2400-volt motor-generator sets with a capacity of 1500 kw. each (Fig. 9). Energy is purchased from the Montreal Light, Heat, and Power Company at 11,000 volts, 60 cycles, 3 phase, and transformed by these units to 2400 volts d.c. for the electric zone.

Chicago, Milwaukee & St. Paul Railway

The delivery of main line and switching locomotives and substation material for the 440-mile electrification of the Chicago, Milwaukee and St. Paul Railway was completed, and there are now in service on this line twenty-four standard freight locomotives each weighing 282 tons; twelve passenger locomotives of similar construction but geared for 60 m.p.h. on level track, weighing 300 tons each with heating equipment; and six freight locomotives equipped with heating equipment for emergency service on passenger trains, weighing approximately the same as the passenger locomotives. There are also two switching locomotives (Fig. 10) weighing 70 tons each, making a total of forty-four units delivered. In order to handle local passenger trains, two of the passenger locomotives have been separated into half units weighing about 150 tons each, so that the number of locomotives available for service is probably 46 instead of 44. Seven new substations on the Missoula Division were also placed in service, thus completing the most extensive steam road conversion in the world.

The Railway Company is rapidly completing the electrification of the Othello, Seattle, and Tacoma division of this main line, extending from Othello in the State of Washington to Seattle and Tacoma on the coast, a distance of 211 miles. Orders were placed with the General Electric Company for the equipment of five substations with apparatus which will be identical with that furnished on the Missoula Division. Five passenger locomotives of a new design, including bipolar gearless motors, are also under construction, and two switchers weighing 70 tons each which are duplicates of those now in service. Line material furnished by the General Electric Company for this section is now being shipped and the poles are set for a greater part of the distance.

* See article in November issue 1917 GENERAL ELECTRIC REVIEW, page 863.

*Automatic Substations**

There were in actual operation between twelve and fifteen automatic substations, and there are under construction in the Schenectady factory more than thirty additional automatic substation equipments ranging in capacity from 200 to 1500 kw.

Electric Locomotives

A number of locomotives ranging in size from thirty to eighty tons were ordered or put into service during the year mainly for switching and light freight service on city, suburban, and interurban railways. Most of these locomotives are of the steeple cab type equipped with four motors, all the weight being on the driving axles. Motor and control equipments have also been sold for locomotives constructed in railway company's shops. The Illinois Traction Company is now building six such locomotives, each weighing sixty tons and equipped with four GE-69 railway motors.

A good example of a standard steeple cab unit is the fifty-ton locomotive (Fig. 11) built for the Northern Ohio Traction and Light Company, which is equipped with four-type GE-257 railway motors and type M control. Two similar units are under construction for the Chicago, North Shore, and Milwaukee R.R. and one for the United States arsenal at Watervliet. Two eighty-ton locomotives with articulated trucks and four GE-69 motors are under construction for the Manufacturer's Railway of St. Louis for handling freight shipments for the Anheuser-Busch Brewing Company.

Car Equipments

The greatest activity in sales of equipment for city and suburban electric systems appeared in the sales of motors for small light-weight safety cars (Figs. 12 and 13). During the year nearly 1500 GE-258 motors were sold for this service, and approximately 900 GE-247 motors were also manufactured for light-weight equipments. Large orders for the above small motors included the following:

- Transit Supply Company, 360 GE-258 motors for Twin City Lines.
- Bay State Street Railway, 400 GE-247 motors.
- New York State Railways, 100 GE-258 motors.
- International Railway Co. of Buffalo, 200 GE-258 motors.
- Philadelphia Rapid Transit Company, 200 GE-247 motors.

The commutating pole ventilated type railway motor known as the GE-249, rating

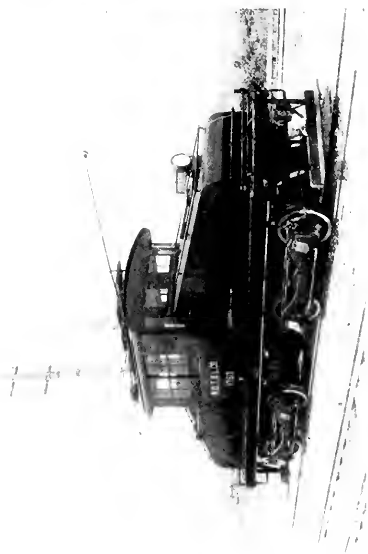


Fig. 11. 50-ton, 600-volt Locomotive, Northern Ohio Traction & Light Company

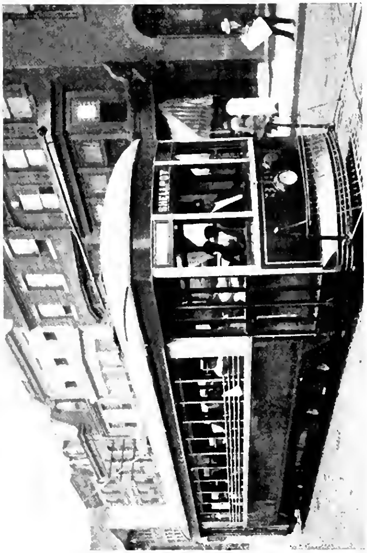


Fig. 12. Typical Light-weight Car Using GE-258 Motors

Fig. 13. Typical Light-weight Car Using GE-247 Motors

Fig. 14. Interborough Rapid Transit Train Equipped with PC Control

43 h.p. at 600 volts was quite popular during the year, especially in foreign countries such as Japan, India, Italy, and Spain, where a large part of the traction systems are narrow gauge for which this motor is particularly adapted. For subway and elevated service, 336 GE-260 motors were contracted for by the Interborough Rapid Transit Company (Fig. 14). Large sales of GE-200, GE-201, and GE-203 motors also continued from a standard line of commutating pole railway motors. The United Railways of Baltimore purchased 320 GE-200 motors, and the Detroit United Railway 200 GE-203 motors.

An interesting order from an historical standpoint was the sale of twenty-four supplementary equipments to be used on the Providence, Warren and Bristol Division of the New York, New Haven and Hartford Railroad. This division was one of the earliest roads to change from steam to electrical equipment, purchasing GE-55 motors in 1899. The latest order includes twenty-four GE-254 motors of the ventilated type to be used on six motor cars.

MINING AND INDUSTRIAL LOCOMOTIVES

Early in the year there was placed in service a 30-ton, 48-inch gauge mine haulage locomotive (Fig. 15) equipped with three 125-h.p., 500-volt driving motors and Type M multiple unit control, and both straight air and hand brakes.

This locomotive is used for main mine haulage and develops 20 per cent tractive effort (12,000 lb.) at 8.8 m.p.h., and is arranged so that two units can be operated in tandem, thereby bringing the two-unit capacity up to 60 tons.

Among the larger units under construction there was one which, when completed, will be the heaviest locomotive of its gauge and height so far built. It consists of a 40-ton, 36-in. gauge, single unit articulated truck locomotive driven by four 500-volt motors, and its equipment includes automatic air brakes and *HC* control which is similar in principle to the well known *PC* control, except that it is operated manually instead of by compressed air.

While this locomotive is intended for surface haulage, its dimensions are limited by the fact that its route includes a relatively low tunnel. Its overall dimensions are: length, 31 feet, eight inches; width, 6 feet, one inch; and height over cab, 9 feet. It will develop 20 per cent tractive effort (16,000 lb.) at 7 m.p.h.

The HC controller referred to above was used for the first time on mine locomotives in 1917. As the locomotive units increased in size with corresponding increments in their current demands it was found that the drum type controllers could not be utilized effectually on account of their limited capacity, while the PC type necessitated the equipment of the locomotives with air compressors for their operation.

Fig. 15. 30-ton, 48-inch Gauge Mine Haulage Locomotive

The HC controller, however, is capable of handling the heaviest currents required by any mine locomotive in service or under construction, and the main contactors are actuated by a cam which is in turn moved by means of a simple hand-operated lever.

This type of controller was developed to handle 250-volt and 500-volt mine locomotives ranging from 15 tons rating to 40 tons.

The reversing and series paralleling drums (Fig. 16) are mounted in separate boxes on top of the case holding the main cam units, but are mechanically interlocked. There is a space between the two parts of the controller to allow the hand brake rod to pass through, and there are two sizes of reversing and series paralleling boxes and two sizes of main controller cases (Fig. 17). The larger size of reversing box is for handling three motors as well as four when tandem operation is desired. The other size is for only two motors. The one main controller case takes six cam units, and the other five. There are also two capacities of cam units which will go in the same spacing, so that there is quite a wide variety of conditions which can be met without any great change of parts.

The contact units are wired and operated in such a manner that six steps are obtained with five units, and by using the extra sixth unit the capacity is doubled although still keeping the same number of steps.

Fig. 16. Locomotive Equipped with HC Control with Covers Removed to Show Arrangement of Contactors

In order to make the controller operate as easily as possible, a ratchet handle is used whereby a 4 to 1 gear ratio may be used. In turning off, the straight 1½ to 1 ratio is used, and in turning on, either this ratio or the 4 to 1 ratio can be used by ratcheting back a little on each point.

In contrast to the exceptionally large sizes already referred to there was produced the smallest practical mine locomotive ever constructed. It is a storage battery unit rated at two tons, for operation on 20-inch gauge, and has a single driving motor which gives an effective drawbar pull of 400 lb. at 3 m.p.h. The battery is carried on a trailer having approximately the same dimensions as the locomotive (Fig. 18).

This outfit was designed for underground service and to meet unusual conditions in mine developmental work. It is used on different levels in the mine, and its exceptionally limited dimensions, viz., overall length 48 inches, width 34 inches, and height 35 inches, and the fact that the step and operators seat are removable, permit its ready transfer in the shaft cage from one level to another.

An important development in storage battery locomotives was the production of a motor (Fig. 19) specially adapted for this service, which rendered feasible the use of single reduction gear drive. Prior to 1917 the motors applied to this type of locomotive were of the light weight, high-speed type originally designed for motor vehicle drive, and double reduction gearing was necessary in order to obtain the low speeds normally required for locomotives. The new motor, which is made in 6 h.p. and 12 h.p. sizes, has the same mechanical characteristics as the motors used on trolley type locomotives, and with a slow speed armature, wound for 85 volts, permits the efficient application of the storage battery energy through single reduction gearing, thereby avoiding the use of the additional gear, pinion, and counter-shaft heretofore required, and eliminating the friction losses they involved, simplifying the mechanical arrangement of the locomotive, and reducing first cost and maintenance charges. The saving in energy consumption is, of course, specially important in that it increases the radius of action of storage battery locomotives for each charge.

MINE HOISTS

While the electrification of mine hoists did not continue at the rapid pace set during

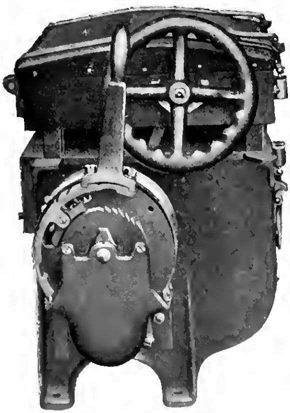


Fig. 17. HC Control Equipment for Mine Locomotive Showing Location of Hand Lever

the preceding year, a large number of motor applications were made in both the coal and metal mining fields, and upwards of 90 equipments of 100 h.p. and above, aggregating over 22,000 h.p., were supplied. The large majority of these were of the induction motor type.

In the metal mining fields there were put into regular service an 1800-h.p. equipment

Fig. 18. 2-ton, 20-inch Gauge Storage Battery Locomotive with Battery Carrying Trailer

at the Elm Orlu Mining Company, Butte, Mont. (Figs. 20 and 21), and a 900-h.p. outfit at the Athens shaft of the Cleveland Cliffs Iron Mining Company, Ishpeming, Mich. Both of these equipments operate on the Ilgner-Ward Leonard system; the flywheel

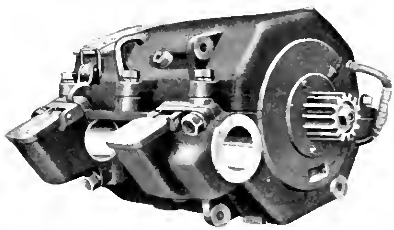


Fig. 19. Type of Motor Designed for Driving Storage Battery Locomotives

set affording, in each case, complete equalization of the maximum balanced duty cycle.

Duplicate equipments of 1400 h.p. capacity, operating on the Ilgner-Ward Leonard system, were installed in the coal fields of West Virginia (Fig. 22). These are located at mines of the Consolidation Coal Company, and are initial installations of this type in the coal fields of the East. They are designed to hoist

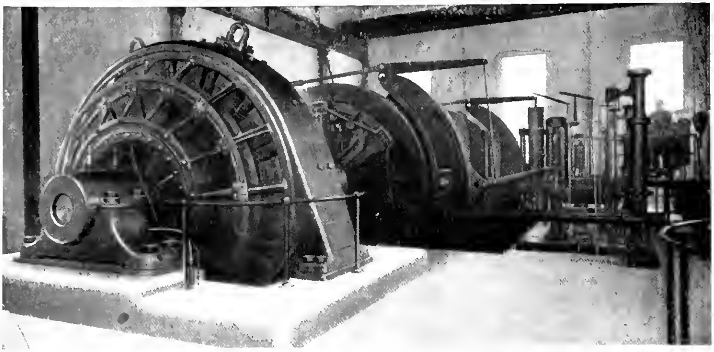


Fig. 20. 1800-h.p. Hoist Motor Driving First Motion Double-cylindrical Hoist, Elm Orlu Mining Company, Butte, Mont.

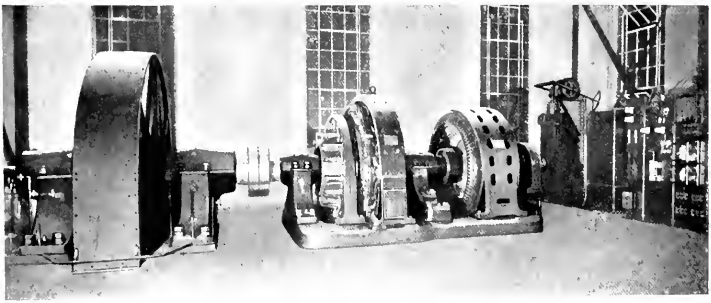


Fig 21. Polyphase Motor-generator Set for Operation of 1800-h p. Hoist Motor, Elm Orlu Mining Company, Butte, Mont.

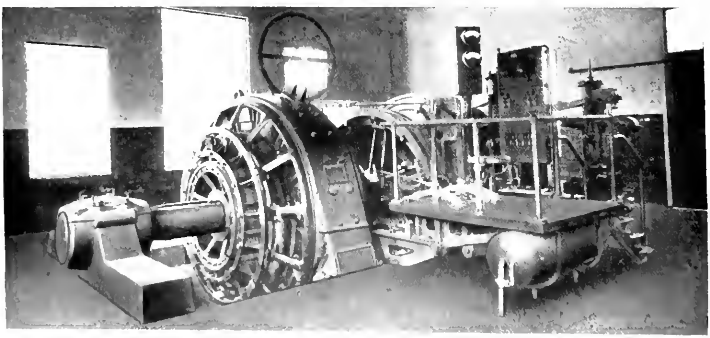


Fig 22 1400 h p Motor driving First Motion Hoist at Mine No 86, Consolidation Coal Company, Fairmont, West Virginia Duplicate Equipment at Mine No. 87

485 tons of coal per hour from a vertical depth of 550 feet, 3.25 tons being handled per trip, with the cages and cars operating in balance.

The hoist motor is rated 1400 h.p., 90 r.p.m., at 550 volts, its armature being mounted on the same shaft with the winding drum. The drum is of the cylindro-conical type, the cylindrical portions being 8 ft. and 11 ft. in diameter. At full speed of the drum the cage speed reaches a maximum of 3100 feet per minute. The slack rope system is employed in which the lower cage is landed and its empty car replaced by a loaded one during the time the upper car is being dumped. The hoist motor is supplied with power through a flywheel motor-generator set whose demand on the power supply is automatically limited to 600 h.p., although the hoist motor develops a peak of 1800 h.p. during hoisting.

BALTIMORE AND OHIO COAL LOADING PIER

This pier was designed and equipped for the rapid transfer of coal from cars to ship-hold with the lowest possible breakage of the coal. Its equipment at the shore end of the pier consists of two steam operated dumpers, capable of handling 45 100-ton cars per hour, which in service have actually dumped 50-ton cars at the rate of 60 per hour.

The coal at the dumpers is deposited into hoppers and distributed by six short feeder belt conveyors to the conveying belt system of the pier. Two radial incline conveyors pivoted at the car dumpers also deliver directly to the power station hopper or to a balancing bin of 6000 tons capacity (Fig. 23). The feeder belts travel at varying speeds and are driven by motors averaging about 15 h.p. in capacity, while the incline conveyors each utilize a 150-h.p. motor.

On the pier itself, which is 700 feet in length (Fig. 24), there are six longitudinal belts traveling at constant speed. The four inner or main conveyors are about 1000 feet long, with 60-inch belts, and on either side of the pier there is a 48-inch, 820-foot conveyor known as a trimmer. These conveyors all move at the rate of 425 feet per minute, each main conveyor being driven by a 300-h.p. motor and carrying coal at the rate of 1500 tons per hour, while the trimmers are driven by 150-h.p. motors and have a capacity of 1000 tons per hour each, making the aggregate delivery of the pier 8000 tons per hour. The pier is 110 feet wide, and the six longitudinal conveyors occupy practically the entire deck space.

The coal is transferred from the four centrally located main conveyors to the hold of the ship by means of four transverse bridges (Fig. 25) arranged to travel lengthwise of the dock, and carrying shuttle conveyors from which the coal is finally delivered. The operation of the entire system of belts serving each of these bridges is centered in the bridge itself by means of remote electrical control, whereby an operator, stationed at the end of the shuttle ram, controls not only the feeder belt speed, but also all the motions of the bridge structure, up, down, in, out, and along the pier, as well as the starting and stopping of the main conveyor belts.

The two trimmer conveyors likewise deliver coal by means of two traveling towers (Fig. 26) which move along the sides of the pier, and are provided with 30-foot projecting booms pivoted at the tower which can swing 270 deg. horizontally and 90 deg. vertically, and deliver the coal from the trimmer conveyors directly into the hold of the ship. The four shuttle belts are driven by 35-h.p. motors, and the two trimmer towers and boom conveyors by 40-h.p. motors.

In addition to the remote control system for the widely separated motor drives, a unique arrangement of feeders furnish current for the various motions of bridges and towers, without resorting to the complicated system of trolley wires or feeder rails with their concomitant contact shoes which would ordinarily be used. This is accomplished by running all feeder cables in conduits along the deck of the pier and bringing them out through bellmouths located at suitable points, whence they pass over rollers to cable reels mounted on the movable bridges and towers. For the bridges, the necessary tension is maintained on the cable by suitable counterweights when winding and unwinding, while in the case of the trimmer towers constant torque motors similar to those used in mining locomotive cable reels are utilized in place of weights.

Current is supplied to the pier substation from the transmission lines of the Consolidated Gas and Electric Company of Baltimore, at 13,200 volts, 3-phase, 25 cycles, and stepped down for the operation of three 500 kw. synchronous converters, which in turn deliver current to the motor groups at 550 volts through eight main feeders.

As an indication of the speed with which ships can be loaded at this pier, 8000 tons of coal were stored in the hold of a steamer in three hours twenty minutes, including all

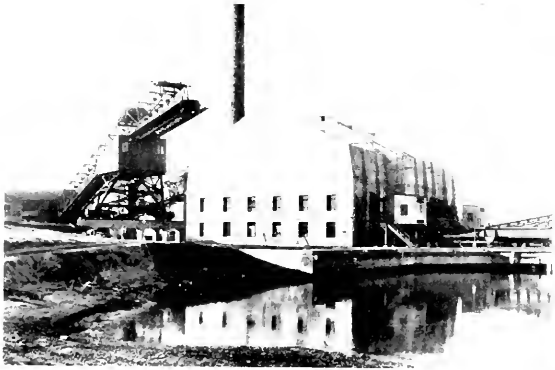


Fig. 23. Radial Incline Conveyor and Balancing Bin

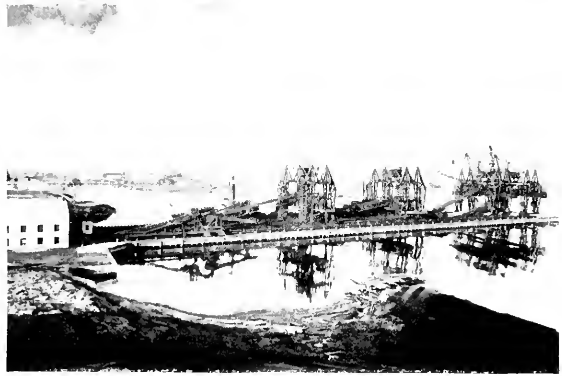


Fig. 24. General View of Pier Showing Arrangement of Transverse Bridges

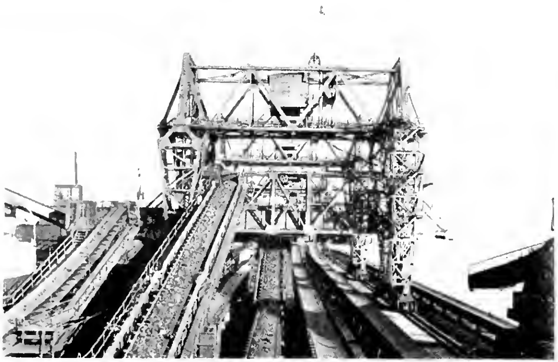


Fig. 25. Transverse Bridge Showing Location and Operation of the Main Conveyor Belts

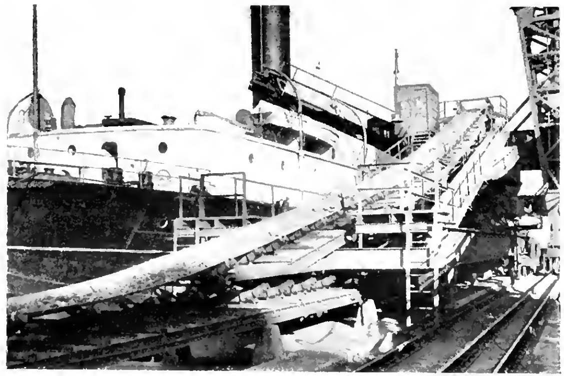


Fig. 26. Trimmer Conveyor Tower Showing Projecting Boom and Conveyor Belt

VIEWS AT BALTIMORE AND OHIO COAL LOADING PIER necessary hand trimming for the proper stowage of the cargo.

CRANES

The production of direct-current crane motors was considerably more than double that of any preceding year, the most notable feature being the increased demand for small crane motors, principally for use in shipbuilding yards.

Among the larger equipments were six overhead traveling cranes of exceptional size. Two of these were of 225-ton capacity the total motor rating of each aggregating 420 h.p.

The remaining three cranes were the largest capacity units of this type ever built, being designed for a full load lift with the main hoist hook of 330 tons at 12.6 feet per minute. The power equipment for each crane comprised two 200-h.p. main hoist motors, two 105-h.p. auxiliary hoist motors, an 80-h.p. and a 30-h.p. motor for main and auxiliary trolley, and two 50-h.p. motors for bridge motion; all these capacities being intermittent ratings.

Two high-speed alternating-current hammerhead coal handling gantry cranes, provided with a unique system of dynamic braking, were installed at the La Belle Iron Works

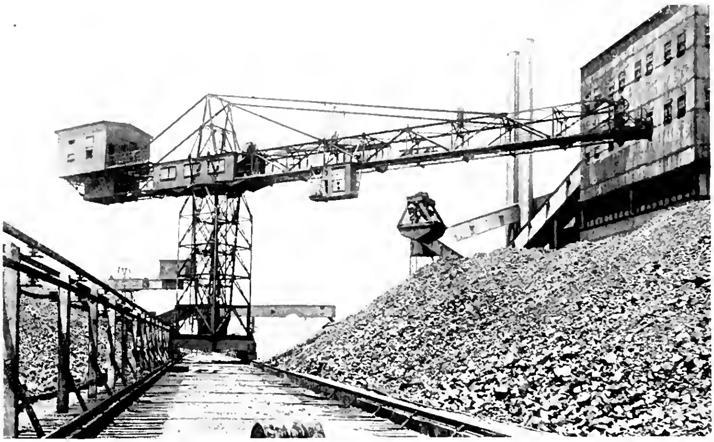


Fig. 27. High Speed A-C. Hammer Head Coal Handling Gantry Cranes

A third crane of the same capacity had motors with a total intermittent rating of 850 h.p. The two main hoist motors each had a rating of 250 h.p. for continuous, and 425 h.p. for intermittent service, giving a hoisting speed for 225 tons of 40 feet per minute, and 120 feet per minute for 60 tons. Due to the high and variable speeds required, the large current demands could not be handled to the best advantage through the usual arrangement of rheostats* and contactors, and Ward-Leonard control was, therefore, provided; this being the first application of this system of control on large cranes.

* See paper by James Farrington and R. H. McLain, Eleventh Annual Convention of Iron and Steel Electrical Engineers, September 10–14, 1917.

plant at Steubenville, Ohio. Each crane (Fig. 27) is equipped with a 375-h.p. slip ring induction motor direct coupled to a 40-h.p. direct-current motor, and hoists a four-ton bucket of coal at 500 feet per minute. The dynamic braking is obtained by combining the small direct-current motor with the alternating-current motor so that the direct-current unit serves as an exciter and gives dynamic braking which is comparable with that ordinarily obtained with direct-current motors on this class of work. *This is the first application on any large scale of this system of dynamic braking for cranes, which is more economical in first cost and has a number of practical operating advantages when compared with the method which utilizes a motor-generator set in addition to an exciter for securing dynamic braking for alternating-current hoist motors. Creeping speeds of 110 feet per minute, lowering, are obtainable with these cranes under ordinary service conditions.

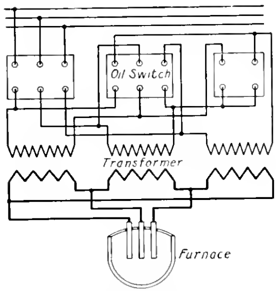


Fig. 28. Connection Diagram of 3-phase Furnace Arranged for Variable Voltage Operation by Means of Changing High-voltage Connections. The High Melting Voltage is Obtained by Connecting High-voltage Windings Delta and the Low Refining Voltage by Connecting them "Y"

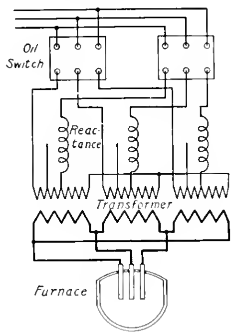


Fig. 29. Connection Diagram of Furnace Equipment. Variable Voltage is Obtained by Means of High-voltage Taps and External Reactance is Provided to be Cut in During the Melting Period

FURNACES

The individual capacity of electric furnaces has remained about the same since 1909, but in 1917, 20-ton furnaces were put in operation and there is every indication of an early advance to a standard maximum of 30 tons. The rate of steel production in these furnaces has been increased by the use of higher capacity transformers and higher voltages, which permit of forcing power into the furnace at considerably higher rates.

Taking for example, the 6-ton furnace, which is the size in greatest general use, the transformer capacity has increased from 900 kv-a. to 1500 kv-a., and even 1800 kv-a. has been proposed, all these capacities being based on 100 volts. In the variable voltage equipments the successful use of 150 volts renders it possible to increase the normal 1500 kv-a. up to 2250 kv-a.

Although 100 volts remains standard for refining, voltages up to 173 have been used for melting, these voltages being obtained either by high voltage taps or high voltage Y-delta, as shown in Fig. 28.

The use of high voltages during melting down permits of decreasing the current for a given input, improves the power factor, and insures higher emergency input when most needed. When it is considered desirable to use external reactance with high voltage taps, the method of using these reactances is shown in Fig. 29.

The most important of the recent developments in electric furnace practice are the improvements resulting in the increased use of the improved G-E system of automatic control.

The control panel is made in three sections, as shown in Fig. 30. The top section contains three shunt relays and three contactor groups; the total number of each being in accordance with the number of electrodes used. The middle section has three contact-making ammeters each provided with dashpots to prevent hunting, and with coils provided with taps which are used to vary the amount of power supplied to the furnace. Beneath are three small dial switches which are connected to the coil taps. On the lowest section there are four d.p.s.t. knife blade switches with fuses, one switch being used for the line and the others for the electrode motors.

Each contactor group consists of three units all mechanically interlocked, two contactors being normally open and one being normally closed.

Facing the panel, the left-hand contactor of any group makes the necessary connections to raise the electrode, while the right-hand contactor causes the electrode to be lowered and the bottom contactor short circuits the motor armature through a resistance, in this way dynamically braking all moving parts and stopping them almost instantly. A higher resistance is connected in circuit with the armature when lowering than when raising, this being done to keep the speed approximately constant.

The shunt-wound electrode motor (Fig. 31) is connected to the line until the desired regulation is obtained, when the motor is disconnected and stopped almost instantaneously by means of dynamic braking, this method giving the simplest and most positive control of the electrode movement. The type of motor used was designed for this particular service, especially in regard to self-lubricating bearings, and ranges in size

Fig. 30. Control Panel for Furnace

from 1 to 1½ h.p. for small equipments to 5 h.p. for 15- to 20-ton furnaces.

STEEL MILLS

The unprecedented expansion which occurred in the iron and steel industry during the years of 1915 and 1916 continued unchecked during the first nine months of 1917. With a few exceptions, the great quantity of electrical equipment purchased by the steel industry during the year comprised the less spectacular but equally important auxiliary drives, control, transformers, motor-generators, etc.

Fig. 31. Shunt-wound Electrode Motor with Special Bearings and Conduit Terminal Box

There was added approximately 60,000 h.p. (normal continuous rating) to the existing capacity of main roll drives installed by the General Electric Company, bringing the present grand total, including only units of 300 h.p. and above, to the impressive figure of 315,000 h.p. This does not include the capacity of auxiliary flywheel motor-generators, speed regulating sets, etc., which are an essential part of many of these main roll drives.

The first reversing mill drives built by the General Electric Company and, incidentally, the largest single unit motors of this type in the country, were placed in successful operation by the Ashland Iron and Mining Company, Ashland, Ky. (Figs 32, 33, and 34), and the Keystone Steel and Wire Company, Peoria, Ill.

Other important reversing equipments were under construction for the Bethlehem Steel Company, Sparrows Point, Md., and the Trumbull Steel Company, Warren, Ohio, each comprising a double-unit consisting of two Ashland Steel type motors, electrically in series on a common base. Two other equipments of similar mechanical design but with even greater normal capacity were being constructed for the Lackawanna Steel Company and the Tennessee Coal, Iron, and Railroad Company. This last equipment consists of a double-unit main roll motor, 5600 h.p. normal rating, guaranteed peak 22,000 h.p., which is supplied with current from a flywheel motor-generator, the generator of which consists of three units electrically in series. Taking into account the guaranteed overloads and speeds, this in the largest reversing drive yet contracted for in this country.

Fig. 32. 2500-h.p., 40 120-r.p.m. Motor-driving 36-inch Reversing Blooming Mill, Ashland Iron Mining Company, Ashland, Ky.

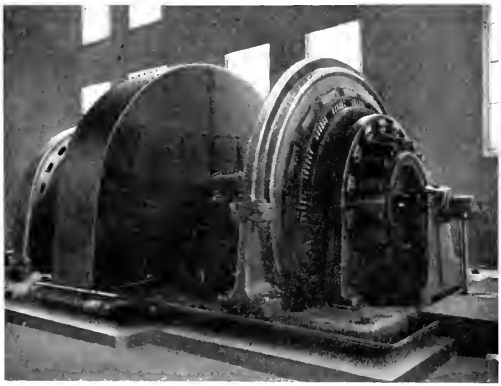


Fig 33. Flywheel Motor-generator Set for Power Supply of Reversing Mill Motor, Shown in Fig. 31, 2000-h.p., 360-r p.m., 2300-volt Motor. 2000-kw., 360-r p.m. Generator, 100,000 lb. Flywheel, Ashland Iron Mining Company, Ashland, Ky.

The question of adjustable speed alternating-current motors assumed increasing importance with the successful installation of the first of the so-called double-range speed regulating sets developed by the General Electric Company. By means of these sets, strictly adjustable and highly efficient speed control can be obtained at all points within the range for which the equipment is designed. The motors may be built for either constant torque or constant horse power throughout the speed range. With the auxiliary set in operation, the normal synchronous speed virtually disappears and strictly continuous control at and near, as well as at points remote from synchronism, is obtained without sacrifice of the desirable maximum torque characteristics common to simple mill type induction motors. There are now in operation, or nearing completion at the factory, 49 of these auxiliary speed regulating equipments, all but one of which involve the now well known modified Scherbius alternating-current commutator machine.

One of the most notable contracts ever closed for steel mill electrical equipment was that with the Tennessee Coal, Iron and Railroad Company, which, in addition to the reversing drive mentioned above, also included one 4000 h.p. unit (constant) with double-range speed regulating set, to give continuous control from 130/155 r.p.m.

Another notable contract with the Tata Iron and Steel Company, Sakchi, India, included in part one 2250-h.p., 450/300-r.p.m. motor with speed regulating set; one 2000-h.p., 200-r.p.m. motor; one 1500-h.p., 250-r.p.m. motor; and one 600-h.p., 550/370-r.p.m. motor with speed regulating set.

This contract also included:

two 5000-kw., one 4200-kw., and one 3000-kw. turbo generators;
three 750-kw. motor-generators;
ten 200-kv-a. transformers;
four turbo-compressors, two of 45,000 cu. capacity, and one each of 28,000 and 37,500 cu. ft. respectively;
four 8700 cu. ft. gas exhausters, turbo driven, about 40 crane equipments, motors and control; also all auxiliary motors for use with mills driven by the above mentioned main roll motors.

Some remarkable records were established in the manufacture of motors: for example, a 4000-h.p., 83-r.p.m., 6600-volt mill type motor with pedestal bearings, base, and 110,000 lb. flywheel on the motor shaft was contracted for on May 10th, and built, shipped, installed, and put into commercial operation by Oct. 17th.

SUGAR MILLS

For this industry there was developed a new system of electric drive of the cane crushing rolls.

As the crushed cane passes through the several sets of rolls (Fig. 35), it is necessary to preserve a given relative speed from roll to roll and also to vary the speed of the mill as a whole without changing the predetermined relative speeds. As the cane feed varies, the torque of the motors will also vary, and means must therefore be provided for maintaining a given speed independent of the load.

Previous practice utilized variable speed induction motors with manual speed control, through the adjustment of the secondary motor resistance, to obtain relative speed control and to reduce the output of the whole mill. With the variation in torque experienced it was found difficult to maintain a given relative speed, and when it was desired to operate at reduced output it was found that the motors required the same power input. Since, however, the refuse cane constituting the fuel was reduced, it was necessary to make up the deficiency with wood or coal.

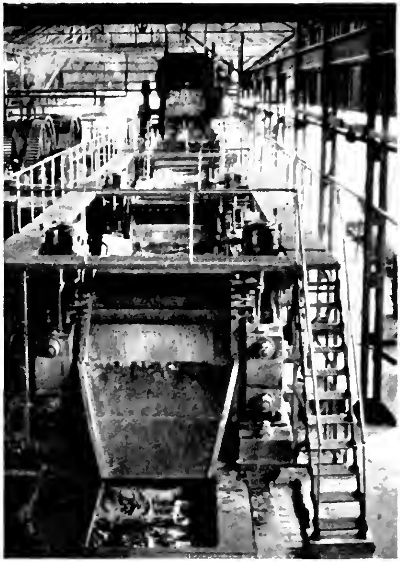


Fig. 35. Typical Cane Crushing Rolls in Sugar Mill

The new system provides for automatic control for the relative speed adjustments and a variable speed steam turbine generator, to give reduced output of the mill. Each motor is served from an individual control panel (Fig. 36) which contains electrically operated switches for regulating the speed of the motor. Master controllers which control the motors through the panels are grouped at a convenient point on the mill platform and give the operator complete control of the motors, excepting that general speed changes of the mill are made at the turbine governors. The several motors driving the individual rolls comprising a mill or tandem are operated from a turbine independent of the sugar house, and speed changes of the mill will not, therefore, affect the normal operation of the motor-driven pumps and miscellaneous drives.

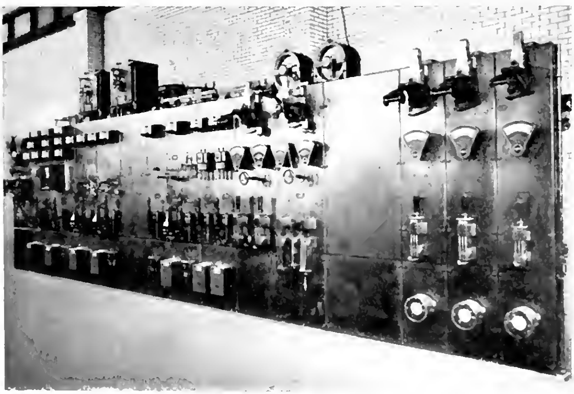


Fig. 34. Switchboard in Motor Room and Sub-station, for 36-inch Reversing Blooming Mill, Ashland Iron Mining Company, Ashland, Ky

On the shaft of each motor is mounted a direct-current magneto type generator which excites the magnet coil of a balanced relay. Contact points on this relay operate a pilot motor which moves the contact arms of a dial switch and thereby varies the resistance in the motor secondary. As the torque on the motor varies, the speed will vary, and thus the change in the voltage of the magneto generator will vary the pull on the arm of the relay and start the pilot motor up in a direction to change the amount of secondary motor resistance to restore the motor speed. A resistance in the magneto generator circuit regulated by the master controllers will provide means for adjustment of the motor speed.

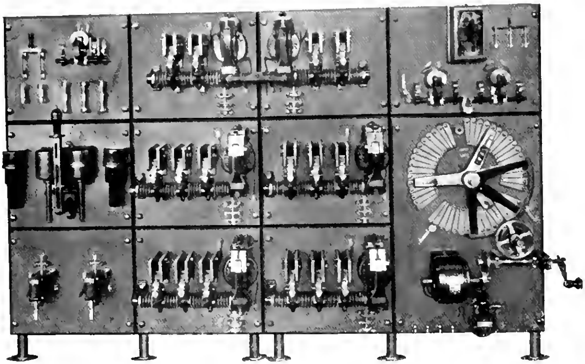


Fig. 36. Main Control Panel for 200-h.p., 440-volt, Three-phase, 45 65-cycle Variable Speed Induction Motor for Driving Cane Crushing Rolls

A change in the speed of the tandem changes the speed of the magneto generators as well, and would ordinarily affect the balance of the relays. Here a rather ingenious idea is used to cause the speed governors to readjust themselves to a change in synchronous speed. The turbine generator is operated at constant excitation with changes in speed. The voltage will, therefore, be in proportion to the frequency. The magnet coil of the relay, which is excited from the direct current magneto generator, is balanced by a coil excited from the alternating-current power circuit. The change in synchronous speed of the motors will therefore cause a proportionate change in both the direct-current and alternating-current coils of the relay, and thereby preserve the balance. The same relative speeds are therefore maintained from roll to roll when the speed of the whole mill is changed.

The automatic control panel provides for one point forward and one point reverse to 75 per cent speed with automatic acceleration, two points forward giving 80 and 85 per cent speed by manual control, and ten points from 85 per cent to normal load speed with automatic speed governor. Automatic control is also included for the two points of manual control and the master controller can be quickly brought to any desired operating point without overloading the motor. While a range in relative speed is provided up to 15 per cent with normal load torque, it is not expected that all of the motors will operate at the same time over this range.

Operation of the whole mill over a range of 30 per cent is done efficiently by means of a change in the turbine generator speed. If the excitation of an alternating-current generator is maintained constant and the speed varied, the voltage and frequency will vary proportionately. An induction motor operating at constant torque from such a generator will draw approximately the same current at

Fig. 37. Load Regulator for Pulp Grinder

different frequencies, and the power input will vary approximately as the speed. The power requirements of the mill are, therefore, in proportion to the fuel delivered by the mill and additional fuel is, therefore, not required.

The pioneer equipment is being installed in Central Cunagua, Cuba.

PAPER MILLS

Under normal operating conditions the current demand on grinder motors is subject to considerable fluctuation, due largely to the changes in load which occur when pockets are thrown on or off and to variations in the water pressure on the pockets.

In order to eliminate these disturbing effects a regulator was designed to maintain a practically constant load on grinder motors at any predetermined value, so that the current variations are held within such narrow limits that their influence on the electric system is practically negligible. This result is accomplished by automatically regulating the water pressure on the pockets by means of a motor operated throttle valve.

The regulator consists of a small induction motor (Fig. 37) which is connected through series current transformers to the feeder lines of the grinder motor. The rotor of the regulator motor rotates through a small angle and actuates the throttle valve of the main water supply to the grinder, thereby automatically reducing the water pressure when the load on the grinder motor starts to increase, and conversely opening the throttle valve and increasing the water pressure to compensate for a falling load.

While this regulating device is simple and strong mechanically, it is also very sensitive to the load changes and smooth in its operation. Actual service tests show that with a single three-pocket grinder, with instantaneous changes in load as great as $33\frac{1}{3}$ per cent, the fluctuations on the driving motor feeder circuit did not exceed 2 per cent.

While the results achieved by the regulator on the electrical system are excellent, the most important effect of its use is the very considerable increase in production secured. Without the regulator the grinder must of necessity operate for varying periods at reduced output when the pockets are being filled, whereas with the regulator in operation such reductions in load are instantly corrected by the changes in water pressure, so that the motor-driven grinder set, when provided with this regulator, is always operating at its maximum rate of production.

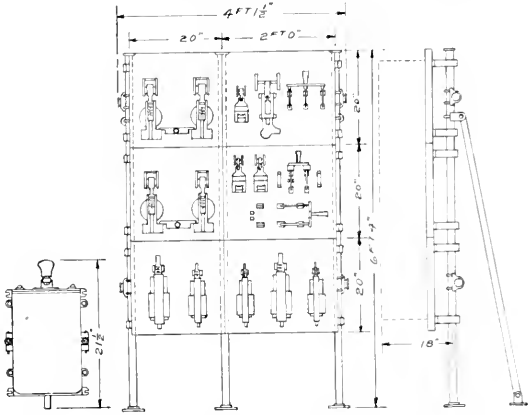


Fig. 38. Outline of Contactor Panel and Controller for Rubber Calender Drive

RUBBER MILLS

There was designed a new system of semi-automatic control for 115/230 volt 4/1 speed double voltage shunt wound motors for driving rubber calenders.

The calender drive is operated through a master controller (Fig. 38) designed to give 115 or 230 volt operation with 18 field points on each voltage for speed regulation.

Throwing the master controller in one direction starts the motor on 115 volts and the field is automatically kept at full strength during acceleration. The accelerating contactors are of the series current limit type and have a load pick-up to insure that they will come in on light loads. When the final accelerating contactor closes, the motor will further accelerate to the full weakened speed at which the controller is set.

If a still higher speed is desirable, swinging the controller handle in the opposite direction will put the motor on the 230-volt line where armature and field acceleration will occur as on the 115-volt line, 18 additional speed points being now available. There is no objection to starting directly on 230 volts if the operator so desires. Bringing the controller to the "off" position will allow the motor to stop.

A feature of the equipment is the "quick stop" device. This is a small enclosed switch with a lever arranged to be operated by a rope, which runs across the calender where the workman can easily reach it. When this switch is pulled all line circuits are broken and the calender equipment is brought to a very quick stop by means of three-point dynamic braking. The calender drive cannot be started again until the stop switch is reset.

The entire system is extremely simple. There is not an electrical interlock on the control panel, and this is an important feature, as in previous methods of control, which utilized electrical interlocking, the sulphur in the rubber mills formed a coating in the interlock contacts, which at times prevented them from making circuit. Mechanical interlocks are used in the new system and afford protection against the possibility of contactors sticking in. The accelerating contactors have a self-contained operating and calibrating coil, and the contactor is cut out after operating.

The motor used for the calender drive is the type RF (referred to under the heading "Direct-current Motors"), which is applied in sizes up to 75 h.p. for single voltage, and 125 h.p. for double voltage equipments. Where the single voltage system is used, either automatic or semi-automatic control can be provided.

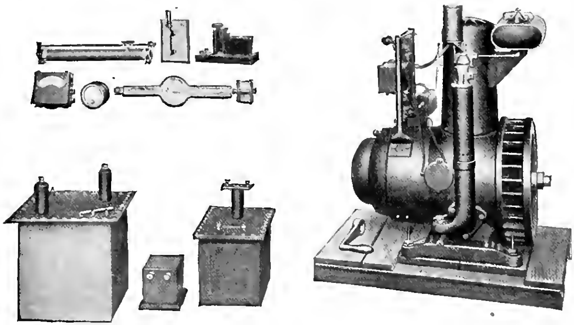


Fig. 39. Portable X-ray Outfit Set-up, Ready for Use

THE RESEARCH LABORATORY

Immediately upon the receipt of news that a state of war existed with Germany, all the facilities of the Research Laboratory were placed at the disposal of the Government authorities by the General Electric Company. As a result of the acceptance of this offer of service, a very considerable proportion of the work done by the laboratory force during the year was directed toward the furtherance of our national aims.

While even a general indication of the character of this work is obviously inadvisable at present, the production of a practical, portable X-ray outfit, which is of interest both from a scientific and humanitarian viewpoint, may be cited.

Also along purely commercial lines reference will be made to applications of the Kenotron.

Portable X-ray Outfit

In order that troops in active service at a distance from base hospitals might have the benefits of X-ray examination promptly available, a complete, compact, portable field service X-ray outfit (Fig. 40) was designed and assembled.

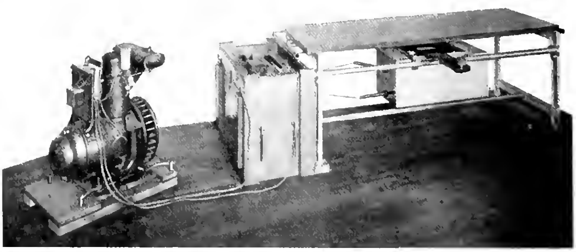


Fig. 40. Separate Units Comprising Portable X-ray Outfit

This was accomplished by a process of elimination through a series of tests which resulted in the final assembly of the most suitable products of several manufacturers which are used in connection with the Coolidge tube.*

* See article by W. D. Coolidge in GENERAL ELECTRIC REVIEW, February 1914.

The equipment (Fig. 40) consists of a single cylinder air cooled gasolene engine direct connected to a 1-kw. direct-current generator provided with slip rings, so that current at a frequency of 47 cycles is supplied; the carburetor of the engine is controlled through a solenoid and the necessary changes in speed are effected by means of a simple resistance unit, located at the head of the operating table when the outfit is being used.

Due to the rectification characteristics of the Coolidge tube no separate rectifier is required. The entire equipment including the operating table can be rapidly assembled or disassembled for transportation, the complete set having a net weight of about 860 lb.

While sets for similar service have been developed in Europe, under the spur of urgent need, the equipment here referred to constitutes the first American portable X-ray outfit.

The Kenotron

This device depends for its operation on the fact that a highly evacuated space containing two metal electrodes (Fig. 41), one of which is incandescent and the other cold, possesses a unilateral conductivity, current passing through the tube only when the heated electrode is negative. The amount of current which can be rectified by such a device increases rapidly with the temperature of the heated electrode, but remains constant as long as the temperature of the latter is maintained constant.*

* See article by Saul Dushman, GENERAL ELECTRIC REVIEW, May 1915.

These characteristics render possible the use of the Kenotron as a rectifier for the production of high-voltage direct-current from an alternating-current source. At present, potentials up to 100,000 volts are secured with standard equipments.

When the Kenotron was first produced in the Research Laboratory several practical applications were predicted for it, and two of these were realized commercially during the past year.

The first of these was in connection with the process of precipitation by means of high voltage direct-current for the reclamation of usable materials in gases or smoke, or the abatement of the nuisance caused by the emission of noxious gases or smoke from flues or stacks. The Kenotron equipment for this service is shown in Fig. 42.

This precipitation process was in use to a very considerable extent for a number of

Fig. 41. High-voltage Kenotron, Maximum Voltage 90,000 d-c. on Half-wave Rectification

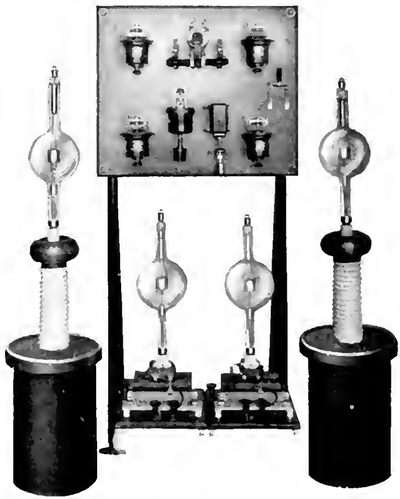


Fig. 42. Switchboard Panel with Protective Devices for use on Kenotron Precipitation Outfits, with Filament Transformers for Kenotrons

years prior to the development of the Kenotron, and the necessary high voltage direct-current was secured by means of a mechanical rectifier, the use of which involved the toleration of certain undesirable features which the use of the Kenotron eliminates.

The operation of the mechanical rectifier is unavoidably noisy and is productive of high frequency surges which are reflected back to the transformer line and impose severe and continuous strains on the transformer windings. These frequencies are so high that it is practically impossible to secure dependable oscillograph records of them. On the other hand, the Kenotron is absolutely noiseless in operation, and the rectification is nearly perfect with maximum voltage fluctuations of less then 15 per cent when delivering direct-current at 100,000 volts.

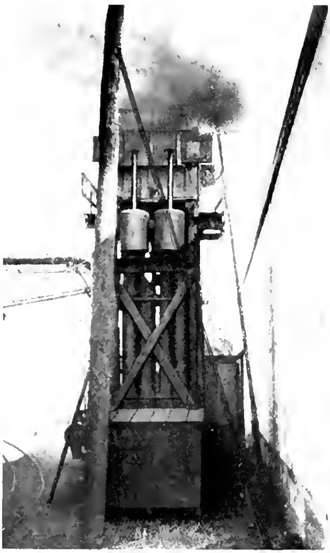


Fig. 43. Experimental Precipitator Used in Electric Precipitation of Coal Smoke—Voltage Off

Fig. 44. Experimental Precipitator Used in Electric Precipitation of Coal Smoke—Voltage On

The application of the Kenotron is shown in Figs. 43 and 44 which indicate the results obtained with an experimental equipment. During the year installations were made for the reduction of blast furnace gases, the suppression of smoke in railroad round houses, and for recovery purposes in the acid plant of a chemical company and in one of the largest copper smelters in the world.

The second application of the Kenotron was in the production of high voltage, portable cable testing sets similar to the one shown in Fig. 45, which was supplied to the Philadelphia Electric Company. This set, which weighs only 1000 lb., is provided with transformers, resistances, spark gaps, and instrument lead terminals, all arranged in one compact portable outfit and gives potentials for testing cables up to 60,000 volts.

TUNGAR RECTIFIERS

In the January 1917 Review the introduction of Tungar rectifiers was mentioned. Since that time some 5000 of these rectifiers have been sold, and the varieties of service to which they have been put have been quite astonishing in view of their comparatively recent development.

They are applied in charging, starting, and lighting batteries on automobiles, motor boats, motorcycles, in private and public garages, in groups as high as ten batteries, many public garages having from three to five rectifiers in service (Fig. 47). They are also utilized for charging the batteries required for the operation of clocks, telephones, fire alarms, etc., and for track and motor batteries on railway signal systems.

In therapeutic work they have been installed in doctors' and dentists' offices; and in connection with X-ray outfits for exciting the fields of synchronous motors. They also supply current for energizing electro-magnets on electric organs and pianos, etc.; in fact, almost daily, some new application for Tungar rectifiers is brought to light.

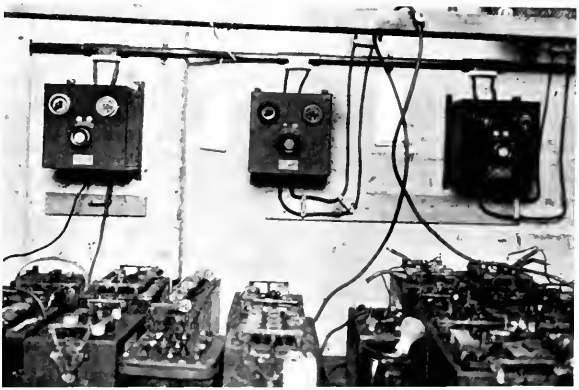


Fig. 47. Installation of 6-amp., 75-volt Tungar Rectifiers in Willard Storage Battery Service Station, Albany, N. Y.

Standard Tungar rectifiers are now built in sizes from 0.1 ampere and 7.5 volts up to 15 amperes and 108 volts, with many intermediate sizes and voltages.

This type of rectifier is so radically different from any other device for similar purposes, and in most cases is so far superior to anything manufactured at the present time for certain applications, that it has met with great favor, and in actual operation has proven very efficient, simple to operate, and generally economical.

* See article by Irving Langmuir in GENERAL ELECTRIC REVIEW, December 1916.

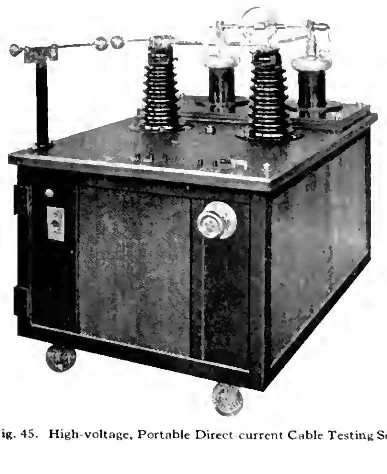


Fig. 45. High-voltage, Portable Direct-current Cable Testing Set

STATIC CONDENSERS

The use of static condensers for the correction of power factor was placed on a practical commercial basis by the design and construction of a number of equipments similar in general arrangement to that shown in Fig. 48.

They consist essentially of groups of condenser sections, each made up of layers of thin paper and tinfoil assembled in oil in metal containers. The sections are individually fused, and in addition an oil switch is provided for connecting to and disconnecting from the line.

It was found that when condenser sections were connected directly across the line no improvement in power factor was secured, but that by inserting a small reactance in series with the condenser the use of practically the entire capacity of the condenser

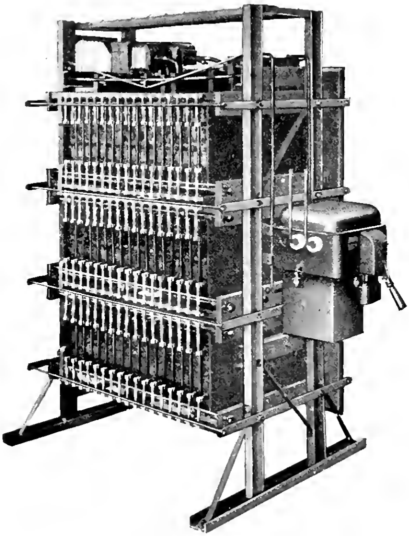


Fig. 48. Indoor Type Static Condenser

sections for power factor correction was possible.

As compared with the synchronous condenser, the static condenser shows exceedingly high efficiencies, the losses being less than one per cent of the total kv-a. regardless of capacity. As there are no moving parts except the simple mechanism of the oil switch, the outfit requires practically no attendance or renewal of parts. It weighs less and occupies less space for a given capacity than a synchronous condenser, and its structural form may be readily modified to meet any reasonable demands caused by space limitations, and, finally, it is noiseless in operation.

A number of equipments are now in successful operation in sizes 50, 100, 150 and 300 kv-a., 40 and 60 cycles single-phase, two-phase and three-phase, and in voltages ranging from 220 to 2300, and equipments up to 400 kv-a., are now under construction.

VOLTAGE STABILIZER

In any electrical system of distribution an instantaneous or sustained increase or decrease of current produces a corresponding voltage change, more or less pronounced, depending on the combined regulation of the line and the transformer from which power is drawn. If the system on which the phenomena take place is one used for power distribution alone, usually no serious results occur. If the system, however, is a mixed one supplying a combination load of lamps and motors, or other power apparatus, then the changes of the voltages do produce serious results in the form of lamp flicker, which may be indicated by either a sudden increase or decrease in the intensity of illumination. Incandescent lamps, being very sensitive to voltage changes, may show marked flicker even if the voltage variation be only one or two per cent. In fact this trouble has become so objectionable that the installation of motors in combination with lamps is considered inadvisable by some of the larger lighting companies.

The stabilizer, which was produced to overcome these conditions (Fig. 49), is essentially a highly 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 by an amount proportional to the voltage drop caused while starting.

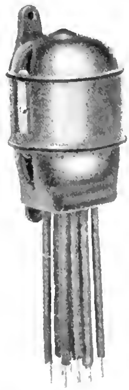


Fig. 49. Voltage Stabilizer for Alternating-current Circuit

It consists of a laminated core into which an adjustable airgap has been interposed. On the middle leg of the core structure are interwound the motor and lamp coils. When starting, the rush of current through the motor coil excites the magnetic circuit of the stabilizer and induces a voltage in the lamp coil which is substantially in phase with the lamp voltage. This action is shown in the diagram, Fig. 50, where E is the voltage added vectorially by the lamp coil in order to maintain E_1, the lamp voltage, at a constant value. If, however, a transformer or reactance is inserted permanently in series with the motor its terminal voltage is appreciably lowered and this might be detrimental, since in some cases full load could not be delivered. In the stabilizer this effect is overcome in two ways: First, by designing so that at normal full load running current the flux density in the iron core is low—this means then a correspondingly low voltage drop; Second, by inserting an air gap in the iron core the apparatus is made highly reactive and most of the drop over the motor coil is in quadrature with the line voltage, except for copper and core loss. These losses can and must be kept low in order to make the apparatus efficient.

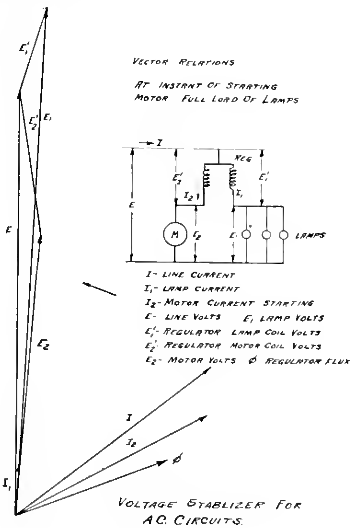


Fig. 50. Diagram of Vector Relations of Voltage Stabilizer

TRANSFORMERS

The circular coil form of construction was embodied in larger sizes, of both self-cooled and water-cooled types than in preceding years. These coils permit the best distribution of the insulation electrically, and their structure has proved to be ideal for resisting the mechanical forces imposed by short circuits.

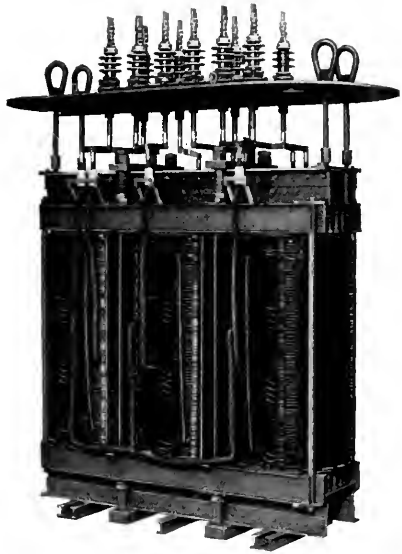


Fig. 51. Core and Coils for America's Largest Transformer—50,000 Kv-a. Output

Another important feature of circular coil construction is the uniform heating and absence of hot spots. This is accomplished through the use of many thin coils, a large number of oil ducts, and the bracings possible with circular coils which do not interfere with good radiation.

The largest capacity transformer (Fig. 51) ever built in America was completed. It is a three-phase auto-transformer unit rated at 25,000 kv-a. with a maximum output of 50,000 kv-a., and was designed to withstand mechanical stresses incident to momentary short circuit. It is intended for stepping up the output of a 45,000-kv-a., 60-cycle turbine generator, from 12,200 volts to 24,400 volts, and exceptionally high efficiencies were indicated during its test; viz., full load, 99.4 per

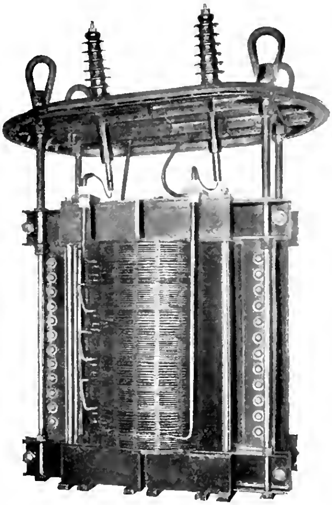


Fig. 52. Largest Self-cooled Transformer—8000 Kv-a, 25 Cycle, 44,000-6600 Volts

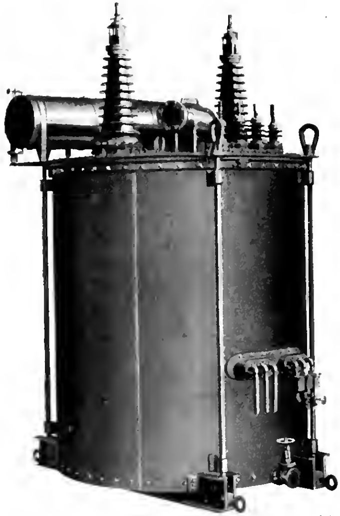


Fig. 53. 10,000-kv-a. Transformer, Equipped with Oil Conservator

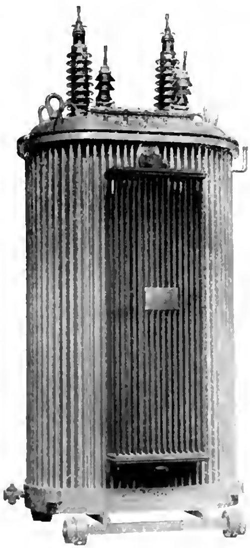


Fig. 54 Combination Radiator and Corrugated Type Tank

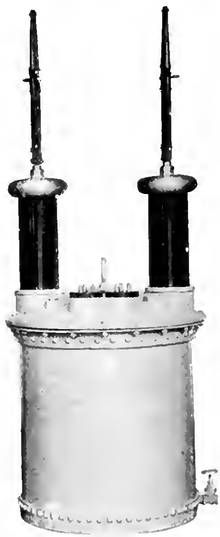


Fig. 55. Standard 15-kv-a., 100,000-volt Precipitator Transformer with Protective Choke Coils

cent; three-quarter and half-load, 99.5 per cent, and one-quarter load 99.3 per cent based on 50,000 kv-a. output.

A number of single-phase self-cooled transformers of record size were produced. Among these were several 8000-kv-a., 25-cycle, 44,000–6600-volt units, three of which are to be used to give a bank output of 24,000 kv-a. They were designed to be proof against momentary short circuit stresses and their interior construction is indicated in Fig. 52.

In the building of these transformers (Fig. 56) a new form of radiator tank was developed which worked out so successfully that many of its features were adopted for some of the largest transformers produced. With this arrangement all joints in the transformer tank are made oil- and air-tight, and an expansion chamber is added as shown in Fig. 53. The transformer tank is completely filled with oil, and all expansion and contraction of the oil is taken care of in the conservator. This construction has two main advantages; viz., moisture due to breathing is trapped and prevented from entering the transformer, and there are no spaces where gas or air may accumulate inside the transformer tank.

In connection with the Cottrell electric precipitation process, already referred to under the subject heading "Kenotron," a

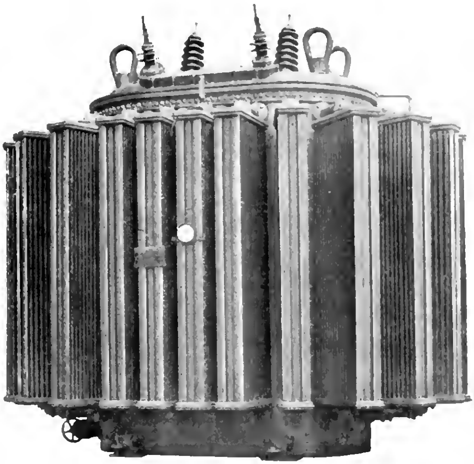


Fig. 56. Radiator Type Tank for 8000-kv-a., 25-cycle, Self-cooled Transformer

other new tank constructions, particularly in combination with the well known corrugated tank. This new tank combines a corrugated tank with external radiators to give a greatly increased cooling surface (Fig. 54).

For electric furnace service an unprecedented number of circular coil transformers were constructed and installed. Some of these have already been in use for considerable periods and have amply demonstrated that the circular coil construction is well adapted to meet conditions involved in electric furnace operation.

Further improvement was secured in the oil conservator tank, and it was applied on

complete line of transformers (Fig. 55) was developed and standardized. There are some unusual features in these transformers due to their high operating voltages and the high frequency surges to which they are unavoidably subjected. Their insulation is exceptionally heavy, extra precautions are taken to eliminate all moisture, and the tanks are oil- and air-tight. The standard line includes 50,000-, 75,000-, 85,000- and 100,000-volt transformers.

Included among the orders received for precipitator transformers, was one for the largest installation of this process that has so far been made.

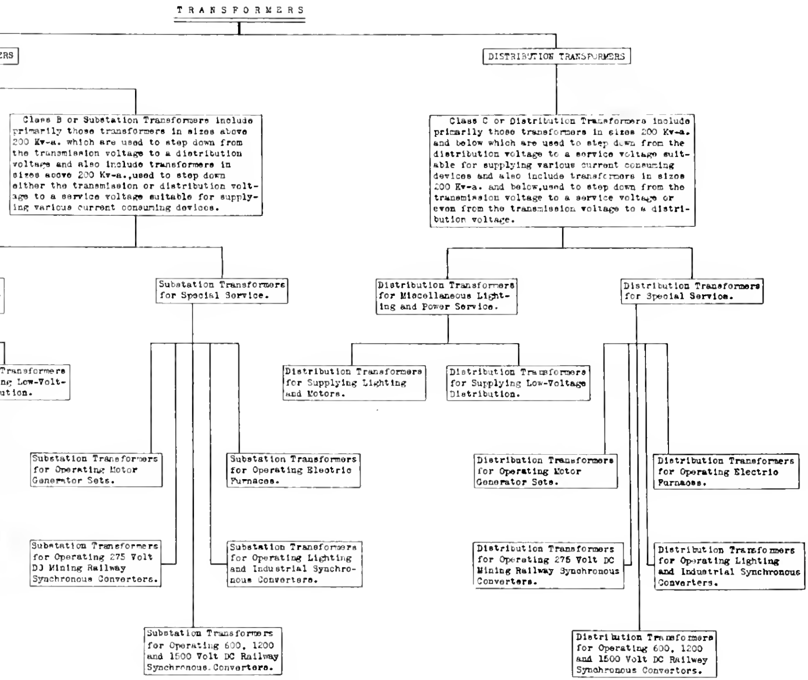


Fig. 57. Classification of Transformers According to Service

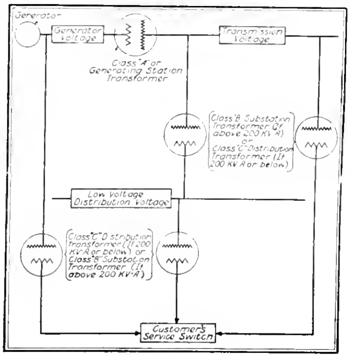


Fig. 58. Location of Transformers on System According to Types

STANDARDIZATION OF CONSTANT POTENTIAL TRANSFORMERS

One of the most important developments from a transformer standpoint was the progress made in more definitely establishing standard ratings for transformers for various classes of service.

In Fig. 57 there is shown the classification of transformers according to their use and application, and in Fig. 58 the relative location of various classes of transformers on a system.

Specific Standardization of Generating Station Transformers

No definite standard voltage ratings have yet been established for generating station transformers, and for the time being, at least, they should be considered as a part of the generating apparatus. All requirements which would tend to complicate the design of such units, and which are not essential from an operating standpoint, should be eliminated.

STANDARD KV-A. SIZES

Kv-a. Continuous Rating at 55 deg. C. Rise (A.I.E.E. Basis)

Self-Cooled		Water-Cooled	
Single-Phase	Three-Phase	Single-Phase	Three-Phase
	300		
	450		
	600		
250	750		750
333	1000		1000
400	1200		1200
500	1500	500	1500
667	2000	667	2000
833	2500	833	2500
1000	3000	1000	3000
1250	3750	1250	3750
1667	5000	1667	5000
2000	6000	2000	6000
2500	7500	2500	7500
3333	10000	3333	10000
5000	15000	5000	15000

TABLE NO. 1

STANDARD VOLTAGE RATINGS FOR SINGLE-PHASE "SUBSTATION" TRANSFORMERS FOR SUPPLYING SERVICE VOLTAGES 575 VOLTS AND BELOW

Standard Line Voltages for Transmission and Low Voltage Distribution	Transformer High Voltage Ratings for Operation from Various Standard Line Voltages	Transformer Low Voltage Ratings for Supplying: Lighting and Motors	Motors	
2300	2200	to 220/110 (3-wire)	or to 220/440	or to 550
	2300	to **230/115** (3-wire)	or to **230 460**	or to **575**
4600	2200/4400	to 220/110 (3-wire)	or to 220, 440	or to 550
	2300/4600	to **230/115** (3-wire)	or to **230, 460**	or to **575**
6600	6600/11430Y	to	220/440	or to 550
	6900/11950Y	to	**230 460**	or to **575**
11000	11000	to	220 440	or to 550
	11500	to	**230 460**	or to **575**
13200	13200	to	220 440	or to 550
	13800	to	**230 460**	or to **575**
22000	22000	to	440	or to 550
	23000	to	**460**	or to **575**
33000	33000	to		550
	34500	to		**575**

TABLE NO. 2

STANDARD VOLTAGE RATINGS FOR SINGLE-PHASE "SUBSTATION" TRANSFORMERS FOR SUPPLYING NOMINAL 2300-VOLT DISTRIBUTION AND MOTORS

Standard Line Voltages for Transmission and Low Voltage Distribution	Transformer High Voltage Ratings for Operation from Various Standard Line Voltages	Transformer Low Voltage Ratings for Supplying Nominal 2300-volt Distribution and Motors
6600	6600/11430Y to	2300
11000	11000 to	2300/4000Y
13200	13200 to	2300/4000Y
22000	22000 to	2300/4000Y
33000	33000 to	2300/4000Y

TABLE NO. 3

STANDARD KV-A. SIZES—SINGLE-PHASE "DISTRIBUTION" TRANSFORMERS FOR TRANSFORMER HIGH VOLTAGE RATINGS, 440 TO 34,500 VOLTS INCLUSIVE

Kv-a. Sizes									
1	440 460 480	550 575	2200 2300 2400	4400 4600 4800					
1.5					6600 6900 7200				
2	440 460 480	550 575	2200 2300 2400	4400 4600 4800					
2.5						11000 11500	13200 13800		
3	440 460 480	550 575	2200 2300 2400	4400 4600 4800	6600 6900 7200				
5	440 460 480	550 575	2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	
7.5	440 460 480	550 575	2200 2300 2400	4400 4600 4800	6600 6900 7200				
10	440 460 480	550 575	2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	33000 34500
15	440 460 480	550 575	2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	33000 34500
25	440 460 480	550 575	2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	33000 34500
37.5	440 460 480	550 575	2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	33000 34500
50	440 460 480	550 575	2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	33000 34500
75	440 460 480	550 575	2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	33000 34500
100	440 460 480	550 575	2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	33000 34500
125			2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	33000 34500
150			2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	33000 34500
200			2200 2300 2400	4400 4600 4800	6600 6900 7200	11000 11500	13200 13800	22000 23000	33000 34500

Specific Standardization of Substation Transformers for Miscellaneous Lighting and Power Service

Standard Types are self-cooled, of either single-phase or three-phase.
Water-cooled, of either single-phase or three-phase.

Standard Frequencies are { 60 cycles per second. 25 cycles per second.

Standard Voltage Ratings for supplying service voltages 575 and below are given in Table No. 1, and for supplying 2300-volt low voltage distribution and motors in Table No. 2.

Standard Taps: Standard single-phase sub-station transformers are provided with four approximately 2½ per cent taps in the high voltage winding

Specific Standardization of Distribution Transformers for Miscellaneous Lighting and Power Service

Standard Types are self-cooled of either single-phase or three-phase.

Standard Frequencies are { 60 cycles per second. 25 cycles per second.

TABLE NO. 4

STANDARD VOLTAGE RATINGS FOR SINGLE-PHASE "DISTRIBUTION" TRANSFORMERS FOR SUPPLYING SERVICE VOLTAGES 600 VOLTS AND BELOW

Standard Line Voltages for Transmission and Low Voltage Distribution	Transformer High Voltage Ratings for Operation from Various Standard Line Voltages	Transformer Low Voltage Ratings for Supplying: Lighting and Motors	Motors
	440	to 110/220	
440	**460**	to **115/230**	
	480	to 120/240	
550	550	to 110/220	
	575	to **115/230**	
	2200	to 110/220	or to 220/440 . . . or to 550
2300	**2300**	to **115/230**	or to **230/460** . . . or to **575**
	2400	to 120/240	or to 240/480 . . . or to 600
	2200/4400	to 110/220	
4600	**2300/4600**	to **115/230**	
	2400/4800	to 120/240	
	6600/11430Y	to 110/220	or to 220/440 . . . or to 550
6600	**6900/11950Y**	to **115/230**	or to **230/460** . . . or to **575**
	7200/12470Y	to 120/240	or to 240/480 . . . or to 600
11000	11000	to 110/220	or to 220/440 . . . or to 550
	11500	to **115/230**	or to **230/460** . . . or to **575**
13200	13200	to 110/220	or to 220/440 . . . or to 550
	13800	to **115/230**	or to **230/460** . . . or to **575**
22000	22000	to 110/220	or to 220/440 . . . or to 550
	23000	to **115/230**	or to **230/460** . . . or to **575**
33000	33000	to 110/220	or to 220/440 . . . or to 550
	34500	to **115/230**	or to **230/460** . . . or to **575**

TABLE NO 5

STANDARD VOLTAGE RATINGS FOR SINGLE-PHASE "DISTRIBUTION" TRANSFORMERS FOR SUPPLYING NOMINAL 2300-VOLT DISTRIBUTION AND MOTORS

Standard Line Voltages for Transmission and Low Voltage Distribution	Transformer High Voltage Ratings for Operation from Various Standard Line Voltages	Transformer Low Voltage Ratings for Supplying Nominal 2300-volt Distribution and Motors
6600	6600/11430Y	to 2300
11000	11000	to 2300/4000Y
13200	13200	to 2300/4000Y
22000	22000	to 2300/4000Y
33000	33000	to 2300/4000Y

TABLE NO. 6

STANDARD RATINGS OF SINGLE-PHASE AND THREE-PHASE "SUBSTATION" AND "DISTRIBUTION" TRANSFORMERS FOR OPERATING 600-, 1200- AND 1500-VOLT D-C. RAILWAY SYNCHRONOUS CONVERTERS

STANDARD TYPES

(a) Single-phase—oil-cooled
(b) Three-phase—oil-cooled
(c) Single-phase—water-cooled
(d) Three-phase—water-cooled

STANDARD FREQUENCIES

(a) 60 cycles per second
(b) 25 cycles per second

Transformer Standard Kv-a. Sizes and Low Voltage Ratings

Kw. Rating Converter	Nominal Unit Kv-a. Rating of Transformer		Transformer's Rated Low Voltage			
			600-volt d-c. Converter		1200-volt d-c. Converter	1500-volt d-c Converter
	Single-phase Bank	Three-phase Bank	Commutating Pole	Non-Commutating Pole	Commutating Pole	Commutating Pole
200	65	200	385 or 445	370	770	965
300	100	300	445	370	770	965
400	135	400	445	370	770	965
500	165	500	445	430	770	965
750	260	780	445		890	1115
1000	350	1050	445		890	1115
1500	525	1575	445		890	1115
2000	700	2100	445		890	1115
3000	1050	3150	445		890	1115
4000	1400	4200	445		890	1115

NOTE.—Transformers having low voltages 370, 385, 770 or 965 for use with three-phase converters and those having 430, 445, 890 or 1115 are for use with six-phase converters.

STARTING TAPS.—50 per cent starting tap will be provided in low voltage winding of all transformers.

INHERENT REACTANCE.—Transformers are designed with 10 to 15 per cent inherent reactance with minimum of 10 per cent.

TABLE NO. 7

Standard Transformer High Voltage Ratings

Standard Line Voltage for Transmission and Low Voltage Distribution	Standard Transformer High Voltage Ratings for Operation from Standard Line Voltages				
	On Full Winding	Approximately on			
		2½ per cent Tap	5 per cent Tap	7½ per cent Tap	10 per cent Tap
		60-CYCLE SERVICE			
2300	2300	2243	2185	2128	2070
		25-CYCLE SERVICE			
2200	2200	2145	2090	2035	1980
		60- OR 25-CYCLE SERVICE			
11000	11000	10725	10450	10175	9900
13200	13200	12870	12540	12210	11880
19100	19100	18623	18145	17668	17190
33000	(33000Y)	(32175Y)	(31350Y)	(30535Y)	(29700Y)

NOTE.—For transformers 165 kv-a. single-phase, 500 kv-a. three-phase, and smaller, taps in high voltage winding will be for reduced kv-a. output at established temperature rise. For transformers 260 kv-a. single-phase, 780 kv-a. three-phase, and larger, taps in high voltage winding will be for full kv-a. output at established temperature rise.

Standard Taps: Standard distribution transformers wound for voltages below the 6900-volt class are not provided with taps. Standard distribution transformers of the 6900-volt class or for higher voltages, are provided with taps in the high voltage winding for approximately 5 and 10 per cent voltage variation.

Exception—Past demand necessitates an exception in the case of transformers of the 6900-volt class for supplying service voltages 600 volts and below.

Standard taps for such transformers are as follows: 6300 6000/5700 based on 6600 to 110/220 or to 220/440 or to 550-volt operation.

6585/6275/5960 based on 6900 to 115/230 or to 230/460 or to 575-volt operation.

6875/6545/6220 based on 7200 to 120/240 or to 240/480 or to 600-volt operation.

Standard Kv-a. Sizes for single-phase distribution transformers for transformer high voltage ratings 440 to 34,500 volts, inclusive, are given in Table No. 3.

Standard Voltage Ratings for service voltages 600 and below are given in Table No. 4, and for supplying nominal 2300-volt low-voltage distribution and motors in Table No. 5.

Specific Standardization of Substation and Distribution Transformers for Special Service Conditions

Under this heading has been classified transformers to operate specific devices and whose ratings and characteristics are very definitely established by the requirements of these specific devices.

Standard types, frequencies, kv-a. sizes and voltage ratings for transformers to operate 600-, 1200- and 1500-volt d-c. railway synchronous converters are detailed in Tables Nos. 6 and 7.

Standard types, frequencies, kv-a. sizes and voltage ratings for transformers to operate 275-volt d-c. mining railway synchronous converters are detailed in Table No. 8.

No specific standards have yet been established covering **transformers for operating lighting and industrial converters, electric furnaces, and motor-generator sets.**

Constant Current Transformers

The constant current transformer for street lighting service which was brought out early in the year differs radically from its predecessors in its appearance and methods of placing insulation. The changes involved were caused primarily by the rapidly increasing cost of the materials used in transformer construction; but the new type, in addition to reducing production costs, weight of material used, and overall dimensions, has at the same time resulted in improved power-factor and efficiency as compared with earlier types.

TABLE NO. 8

STANDARD RATINGS OF SINGLE-PHASE DISTRIBUTION TRANSFORMERS FOR OPERATING 275 VOLT D-C. MINING RAILWAY SYNCHRONOUS CONVERTERS

STANDARD TYPE

Single-phase—Oil-immersed—Self-cooled

STANDARD FREQUENCY

60 Cycles per Second

Standard Transformer Kv-a. Sizes, High and Low Voltage Ratings

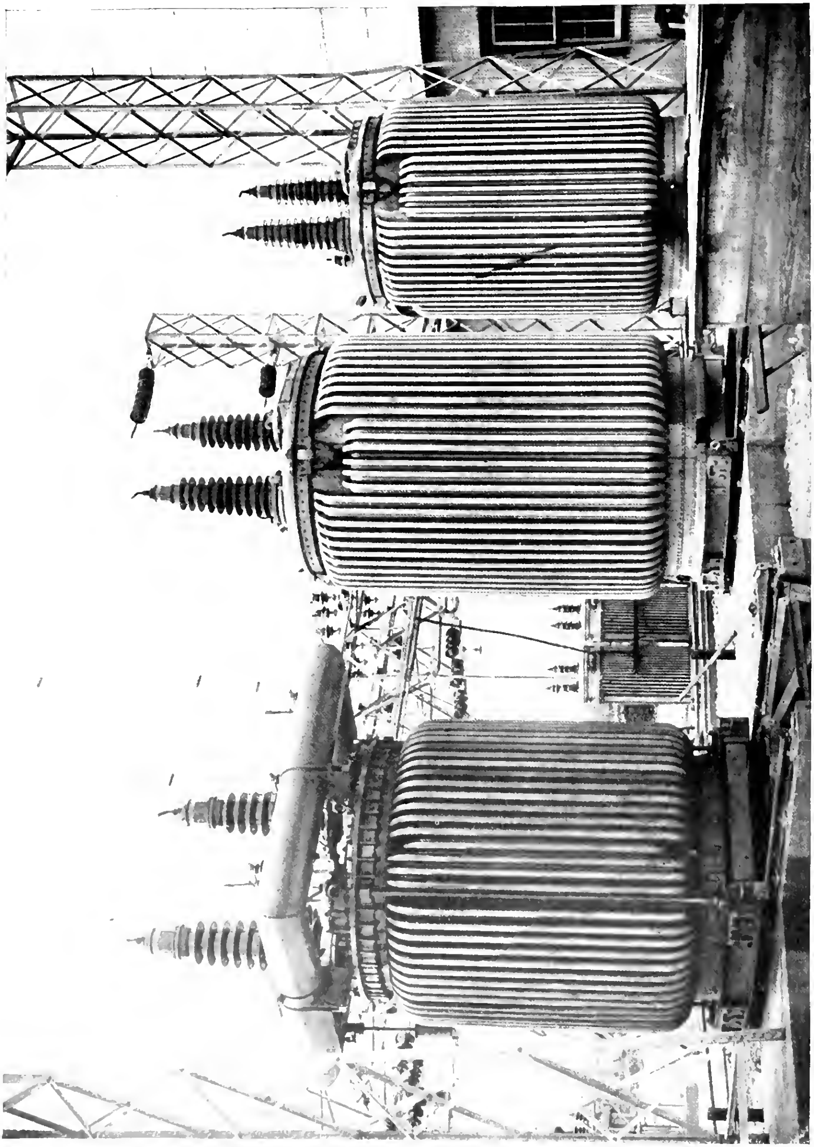
Kw. Rating of Converter	Nominal Unit Kv-a. Rating of Transformer	Standard Line Voltage for Low Voltage Distribution	STANDARD TRANSFORMER HIGH VOLTAGE RATINGS FOR OPERATION FROM STANDARD LINE VOLTAGES					Transformer's Rated Low Voltage
			on Full Winding	Approximately on 2½ per cent Tap	5 per cent Tap	7½ per cent Tap	10 per cent Tap	
100	35	2300	2300	2243	2185	2128	2070 to	178
150	50	2300	2300	2243	2185	2128	2070 to	206
200	65	2300	2300	2243	2185	2128	2070 to	206
300	100	2300	2300	2243	2185	2128	2070 to	206

NOTE.—Transformers having low voltage of 178 are for use with three-phase converters, and those having low voltage of 206 are for use with six-phase converters.

STARTING TAPS.—50 per cent starting tap to be provided in low voltage winding.

HIGH VOLTAGE TAPS.—Taps in the high voltage winding will be for reduced kv-a. output at established temperature rise.

INHERENT REACTANCE.—Transformers are designed with 10 to 15 per cent inherent reactance with a minimum of 10 per cent.



Three 1000-kv-a., 100,000-volt Transformers, showing at Left an Oil-filled Transformer Equipped with Oil Conservator

Before the changes were made the frame and base of the constant current transformer were made up of castings held together by steel rods and nuts, and the form-wound coils were heavily insulated. The initial improvement, which occurred in 1916, eliminated the castings by the substitution of angle iron for frame and base, effecting a reduction of about 20 per cent in weight. A protective casing of extruded metal or wire net was also made part of the regular equipment.

In 1917 a new design was produced in which the main insulation was placed on the core (Fig. 59) instead of on the coils; this being a radical departure from previous practice. As these transformers are air-cooled and use exposed coils, they are not intended for use on circuits with primary potentials exceeding 5000 volts.

Phase displacement transformers, used for pole mounting out-door service on lighting circuits, have comparatively low power-factor, and require changes in taps whenever changes in voltage conditions occur, if good operating efficiencies are to be maintained.

These disadvantages were overcome in the development for this service of an oil-cooled constant current transformer (Fig. 60), having the same characteristics as those for indoor use.

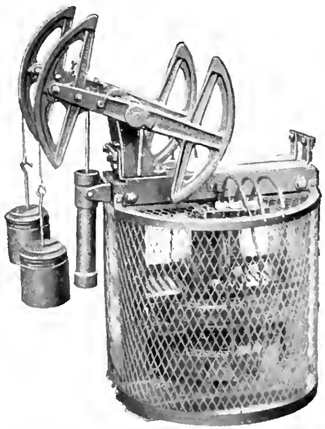


Fig. 59. Air-cooled Constant Current Transformer

Induction Voltage Regulators

Toward the end of the year there was under construction for the Hartford Electric Light Company, Hartford, Conn., the largest induction voltage regulator ever built. It is rated at 1000 kv-a. for use on an 11,000-volt, 60-cycle circuit, and is cooled by forced oil circulation.

Fig. 60. Oil-cooled Constant Current Transformer

A notable high voltage installation consisted of seven 160-kv-a., three-phase, 50-cycle, 11,000-volt automatic water-cooled regulators which were supplied to the Southern

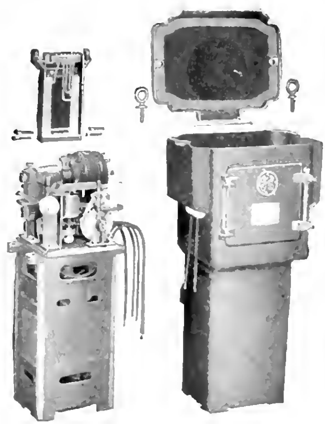


Fig. 61. Improved Pole Type Regulator

California Edison Co., of Los Angeles, for use on 11,000-volt feeders. They maintain voltage regulation on circuits largely devoted to supplying current for electric ranges.

While no changes occurred in the electrical characteristics of pole type regulators, the mechanical details were improved in a number of ways (Fig. 61). Some of the more important of these new features can be summarized as follows: The operating motor was provided with ball bearings, and the current consumption was reduced to 30 watts, and lower temperature rise secured; the motor can be removed and replaced without lifting the regulator from the tank or removing it from the pole; the limiting device was re-designed to eliminate the need for adjustment, and absolutely prevents overtravel of the regulator segment; while a new method of assembly of the cores minimizes shifting of the punchings and resultant noise in operation.

Fig. 62

Current Limiting Reactors

The cast-in concrete method of construction was further extended during the year to larger sizes of current limiting reactors. The largest unit built was a single-phase, 2300-kv-a. reactor to give 16⅔ per cent reactance in a 12,000-volt, 25-cycle circuit.

LIGHTNING ARRESTERS

The adoption of sphere gaps in combination with horn gaps for use with aluminum lightning arresters constituted a definite advance in the art of electrolytic arrester design, inasmuch as their use was found to insure a very considerable reduction in the time-lag of the arrester equipment as compared with that secured with horn gaps alone.

In order to determine the spark-lag values of different forms of gaps, exhaustive tests were made (Figs. 62 and 63) with needle-gaps, horn-gaps, and sphere gaps, all connected in parallel to insure identical stress conditions and subjected to high-potential, steep-front voltage waves. *The results showed definitely that the electrical stresses on the insulation of generating, transforming and distributing apparatus, protected by electrolytic arresters, could be greatly reduced by the addition of sphere-gaps to the equipment heretofore used.

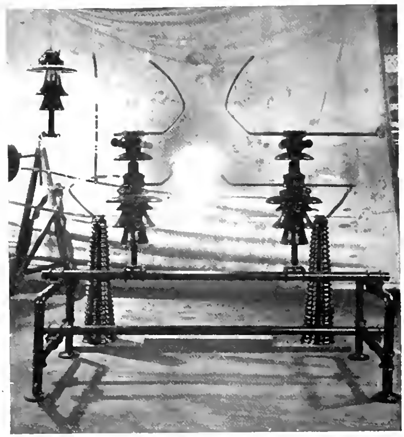


Fig. 63

All G-E aluminum lightning arresters for use on circuits above 14,000 volts (Fig. 64) are now provided with sphere-gaps.

SWITCHING APPARATUS

Considerable progress was secured tending toward the perfection of previously developed safety-first devices, and numerous detail improvements were made in standard equipments, especially in the line of high potential switching apparatus.

Among the radically new devices there were certain relays which possess features of exceptional interest. The first of these is a single unit plunger type overload relay which has a number of decided advantages as compared with older types, while at the same time retaining all their good features. In the new relay better mechanical and elec-

* See article by V. E. Goodwin in G-E Review, Aug., 1917.

trical characteristics have been secured, the number of parts used has been materially reduced, and standardization has been carried to unusual lengths.

The interchangeability of parts for different service operations can be appreciated by reference to Figs. 65, 66 and 67, and it will be noted that all of these relays are made from the same general parts, so that any one of the three types can be converted into any one of the other two by simply adding or omitting the bellows, or by changing the spring in the barrel which carries the moving contact mechanism. As far as the external parts are concerned, instantaneous, inverse time-limit and definite time-limit are alike.

As compared with the older types of relays, the new unit has bellows of greater diameter, and the stroke is also slightly greater so that the amount of air to be displaced during its operation is considerably increased. This produces better and more nearly uniform results.

The fixed contacts may be adjusted to give simultaneous contact on both sides, and the carbon cone on circuit closing relays is so held that it cannot get out of adjustment and neither can it be assembled incorrectly as regards adjustments. These fixed contacts can be removed by the removal of two holding screws.

Fig. 65. Instantaneous Circuit-closing Relay

Fig. 66. Inverse Time-limit Circuit-closing Relay

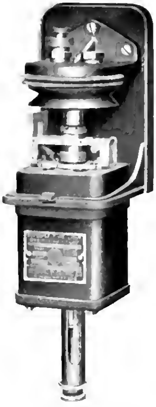


Fig. 67. Inverse Time-limit Circuit-opening Relay

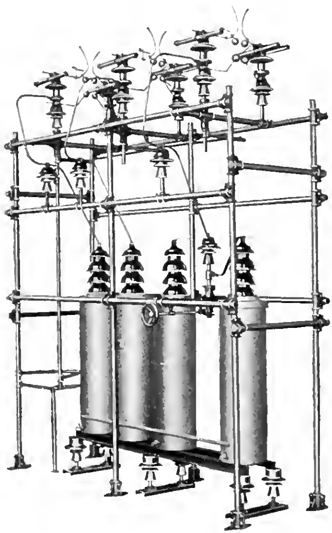


Fig. 64

The stop of the plunger rod is adjustable so that it is possible to produce a definite minimum time on the time-current curve of inverse time-limit overload relays. If necessary, the operating coil can be removed without disturbing the upper parts of the relay.

The calibration is locked by means of a slotted member which is held in position by a spring, and in order to change the calibration it is only necessary to push up on the calibrating screw and turn it. After the relay is adjusted this locking feature returns automatically to the locked position. This detail constitutes a considerable improvement, as in the older types of relays such adjustment required the use of a wrench.

These relays are built in single-pole units only and are intended for the control of a single circuit, circuit-closing and circuit-opening, and their accuracy is not affected by commercial variations of frequency.

In connection with an arc ground suppressor there was designed a new balanced phase selective relay (Fig. 68) for operation from three potential transformers or from a combination of condensers and potential transformers. The arc ground suppressor consists essentially of this relay and three single-pole electrically-operated circuit breakers which are interlocked to prevent the closing of more than one breaker at a time.

The usual and most accurate method of tripping oil circuit breakers is by means of release or trip coils connected to the second-

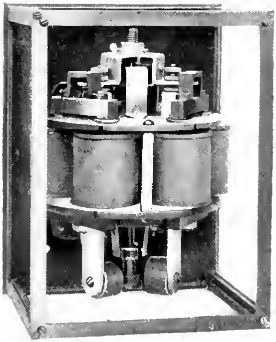


Fig. 68. Phase Selective Relay for Arcing Ground Suppressor

aries of current transformers, which may also supply current to meters and instruments, or they may be especially designed for tripping purposes only.

When the cost of such current transformers is excessive, due to high potential of the circuit, it is advisable for reasons of economy to use some other method. For this purpose the high tension series relay[2] shown in Fig. 69, was developed for use on circuits of 15,000 volts and upward. The benefits secured by this method of tripping are as follows:

The relay solenoid is mounted on a high-voltage insulator and is located between the line and the relay contacts and adjusting parts, and this keeps the high tension leads away from adjacent apparatus. The long operating rod shown introduces an ample factor of safety, and will not warp or buckle as it is constantly under tension. The inverse time element is in an oil dashpot mounted on the frame which holds the tripping contacts, and the calibration can be adjusted while the relay is in service. The connecting rod between the handle and the relay is of the proper length for the voltage of the circuit, which permits the tripping switch and time-limit details to be located where they can be most easily adjusted without danger to the operator.

A reverse power relay[1] for operation on polyphase circuits was constructed along the lines of an induction meter, as shown in Fig. 70. It is made in polyphase units with circuit-closing contacts for instantaneous trip. If time delay action is desired, the time and current setting of the overload relay, which must be connected in series with the reverse power limit contacts, will determine the action of the combination.

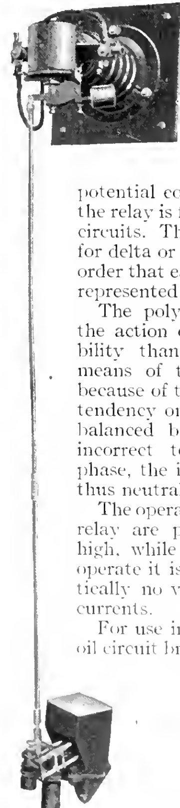


Fig. 69. High Voltage Series Relay

The relay is operated by three separate driving elements, each having a current coil and a potential coil, irrespective of whether the relay is for quarter- or three-phase circuits. The third element is required for delta or ungrounded Y circuits, in order that each phase may be properly represented in every short circuit.

The polyphase construction gives the action of the relay greater reliability than could be obtained by means of three single-phase relays, because of the fact that any incorrect tendency on the part of one phase is balanced by a similar or opposite incorrect tendency on some other phase, the incorrect tendencies being thus neutralized.

The operating characteristics of this relay are permanent, the torque is high, while the energy required to operate it is small and there is practically no vibration even with heavy currents.

For use in connection with air and oil circuit breakers, a hinged armature low-voltage release (Fig. 71) was designed. This type has a coil with a soft iron pole piece mounted in an iron case, the cover of which consists of an armature hinged at its lower end (Fig. 72). When the armature in dropping reaches an almost horizontal position it pushes a trigger down and releases the toggle mechanism. This in turn causes two tension springs to operate a lever with considerable force, and the lever,

[2] See article, G-E REVIEW, Oct., 1917, page 826.
[1] See article, G-E REVIEW, Nov., 1917, page 898.

by striking a hammer blow against the tripping latch of the air or oil circuit breaker, opens the circuit.

As compared with previous low-voltage release equipments this new device has certain advantages, among them being its positive action on reduction of voltage and the fact that the armature will drop at the predetermined point and operate the trigger no matter how slowly the voltage may decrease.

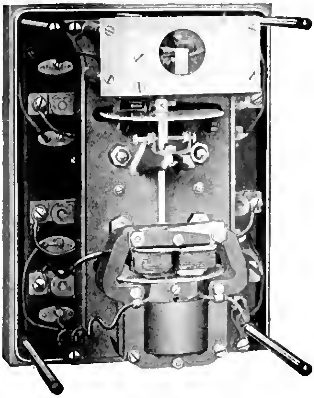


Fig. 70. Induction Polyphase Reverse Power Relay with Cover Removed

If, in starting the motor, the operator does not set the armature up against the pole piece, which is the position from which it should drop on low voltage, the armature will drop immediately when the hand is withdrawn, and trip the breaker.

In connection with the production and standardization of safety-first equipments, a new line of compact, self-contained motor pedestals (Fig. 73) was developed. They are designed particularly for the control of alternating current feeder or motor circuits.

The panels occupy small space and are easy to install. They can be set up singly or in groups and can also be moved readily from place to place as desired. After being put in place the pedestals are secured by being bolted to the floor.

The framework consists of four angle iron corners, and steel plates which hold the angle irons in position serving as mountings for the apparatus in the interior of the pedestal. The back is a sheet steel plate, removable to allow access to the interior.

The apparatus mounted on the pedestal varies according to the duties to be performed, but that illustrated (Fig. 73) consists of voltmeter, ammeter, and watthourmeter on the front; current transformers and potential transformers, oil circuit breaker and disconnecting switch in the interior.

The voltmeter and ammeter are mounted on a cast base above the breaker, and with the front edges of the instruments flush with the casting. Back of the instruments in the interior of the housing are spring contacts which make contact with the instrument studs, so that after removing the mounting screws the instruments can be removed from their support without disconnecting the leads.

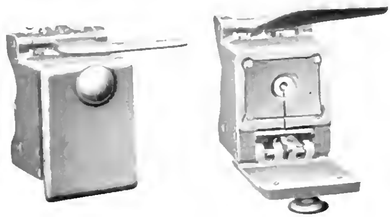


Fig. 71. Low Voltage Release, Armature Up
Fig. 72. Low Voltage Release, Armature Down

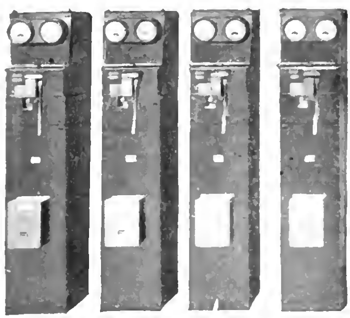


Fig. 73. Safety First Induction Motor Pedestals

When the instruments are replaced, the connections to them are made automatically. The instrument resistances are mounted behind the instruments.

As soon as it became standard practice, in accordance with A.I.E.E. recommendations, to furnish temperature coils with all alternating-current machines having a stator core of 20 inches or more in width, or a voltage of 5000 or higher, and a capacity of 500 kv-a. or greater, the obvious advantage of having a

Fig. 74. Temperature Indicator Panel

compact self-contained equipment for securing direct-reading temperature indications was recognized. This resulted in the construction of the temperature indicator equipment* shown in Figs. 74 and 75, which affords a convenient and rapid means of indicating continuously at the switchboard the temperature of the various portions of the windings of electrical machinery under operating conditions.

The operation depends on the variation of resistance of a copper resistor placed in a slot of the machine stator, in contact with the insulation of the winding, or in any other location external or internal where the resistor may be protected by suitable insulation from the conductors. The increase or decrease of temperature of the windings causes a corresponding change in the resistance of the coil. This change of resistance is indicated by a sensitive instrument, the scale of which is graduated in degrees Centigrade and indicates directly the temperature of the windings.

*See article, G-E REVIEW, May, 1917, page 380.

The temperature indicator is a direct current differential voltmeter with three terminals. One of the windings is in series with a coil of manganin, having a resistance equal to that of the temperature coils, usually at 80 deg. C., and the other winding is in series with the copper temperature coil itself. When the temperature in the copper coil rises, the current in the branch of the circuit carrying the temperature coil decreases, causing a corresponding deflection toward higher temperature marking on the scale of the indicator. The reverse occurs when the temperature of the temperature coil falls. The scale of the standard instrument is adjusted with a range of 20-120 deg. C. or 0-90 deg. C. and marked in single degree divisions.

HEATING APPLIANCES

In the operation of circulation water heaters, especially in districts where the water is very alkaline, the heaters have a tendency to become clogged due to the accumulation of scale. To minimize the inconvenience of this, a sheathed wire heating unit of the immersion type in cartridge form was developed. This unit is arranged so as to be easily removable and the accumulated scale can be readily knocked off. The sheathed wire is formed

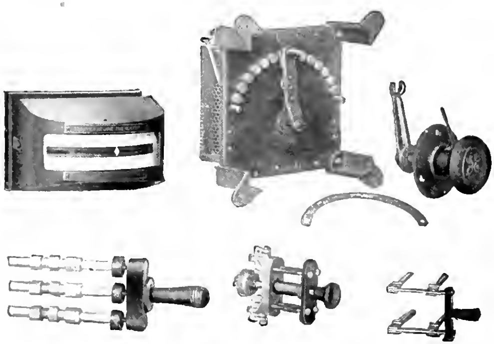


Fig. 75. Parts of Temperature Indicator Equipment for Mounting on Panel

into a solid cylinder and makes a simple and substantial form of heating element.

The unit carries its own terminals and terminal-housing (Fig. 76) and is furnished with a standard pipe thread for insertion in standard pipe fittings. It is evident that it can be used separately as an immersion heater inserted in any tank for heating not only water but other liquids, and therefore is suitable for numerous applications in the industrial arts.

In order to have hot water when wanted and to have the current turned off when not required for heating the water, a very satisfactory, positive, and simple electric thermostat was developed, which depends for its action on the buckling of a diaphragm, actuated by a liquid which expands under heat. This thermostat (Fig. 77) will operate within limits of 10 degrees and can handle substantial amounts of current.

Such a thermostat, of course, is not only applicable to household tanks, but on account of its close regulation it can be utilized effectively for a great variety of industrial purposes where it is important to maintain water or other liquids at constant temperatures.

Many of the electric bake ovens hitherto used in small commercial bakeries and in hotel and institutional kitchens, have been adaptations of portable gas ovens. A new type of electric bake oven (Fig. 78) was designed solely from the standpoint of electric baking, having in mind the conditions involved in bakeshop work and the proper

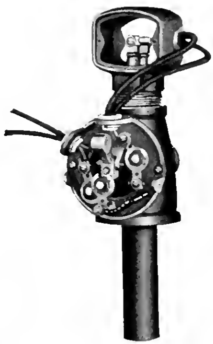


Fig. 76. Electric Circulation Water Heater
Fig. 77. Thermostat for Control of Water Heater

application of electric heating elements for this service. These ovens are built in 3-, 4- and 6-shelf sizes, having a capacity of 50, 80 and 150 loaves per hour, respectively.

The heating elements are heavy sheathed wire coils of great durability, but are easily replaceable; they are self-insulated and require no porcelain or other compound insulating support. The heaters are located in the bottom of the oven and the heat is distributed by the circulation of the air up through channels in the sides.

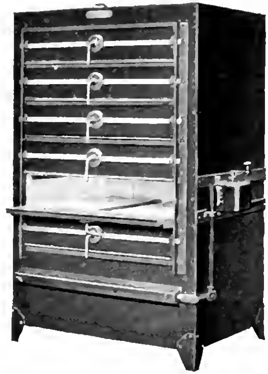


Fig. 78. Bakers Oven with Rotary Heat Controller

A two-inch lining of "Resisto-Therm" heat insulation, together with close heat control, allows the oven to be operated at a minimum cost. The heat control is effected by a small rotary controller. All connections, wiring, etc., are enclosed and provision is made for a conduit connection of the feed wires.

Many bakers are accustomed to using baking tile on the shelves of their ovens and this new design has been arranged to provide such shelves to give the oven more thermal storage.

The successful construction of a new heavy duty electric range (Fig. 79) for hotel service was chiefly due to the development of sheathed wire and to the heavy cast-in heating unit which can be made with it for the cooking top.

Experience has also shown that the frame of the range must be of heavy angle iron and sheet metal construction; oven doors and their hinges must stand hard service; the wiring must not give any trouble from grounding, abrasion, over-heating or defective connections; and the switching arrangement must be simple, substantial and convenient. These points are well embodied in this new range.

For the operation of this range, 220 volts has been selected rather than 110 volts, in order to reduce the amount of copper required for the outside wiring and the size of the internal conductors, and also to bring the range within the scope of application of

Fig. 79. Heavy Duty Hotel Range

rotary snap switches. The snap switches used have new indicating handles, the position of which tells at a glance whether the switch is on or off, or at what degree of heat the heating elements are operating.

On submarines, the only really practical and satisfactory method of cooking is by electricity. This minimizes fire risk, danger of explosions, and avoids uncomfortable kitchen temperatures.

Based on earlier experience, a new design of submarine range was developed (Fig. 80). It is made in sections so that if necessary it can easily be taken in and out through the necessarily small hatchways. The central section consists of the oven and the hotplates on the cooking top. One side section contains a coffee tank, and the other a hot water tank. The hotplates are of the cast-in sheathed wire construction, so successfully used on hotel ranges. The oven is equipped with one open-coil sheathed wire unit, located in the bottom, and the coffee and water tanks with units, in cartridge form, of the sheathed wire swaged type. Each group of units is controlled by a rotary snap switch, located below the oven in a self-contained switchboard. The connections are very accessible and easily made.

LIGHTING

As compared with several preceding years, there were relatively few new developments in incandescent lamps of a character which permits of brief description, but there were many minor improvements which tended to strengthen the lamps mechanically and maintain their quality in the face of rising costs of materials and labor. The scarcity and variability of certain materials utilized in their manufacture also imposed some substitutions and process changes.

The most notable lamp brought out during the year is that developed especially for moving picture projection (Figs. 81 and 82). This development involved not only the production of a new low-voltage Mazda C lamp with an especially arranged filament, but also of a new optical system for the projector, arranged to utilize a larger proportion of the light, together with devices for substituting a new lamp at burnout, and control apparatus for supplying proper voltage from commercial circuits.* A prismatic condensing lens efficiently utilizes a wider angle of light than the types formerly in use, while a spherical mirror placed behind the lamp, not only utilizes light which would otherwise be lost, but also gives a more uniform light source (Fig. 83). This combination of lamp, lens and mirror, has been successfully applied to moving picture machines projecting pictures as large

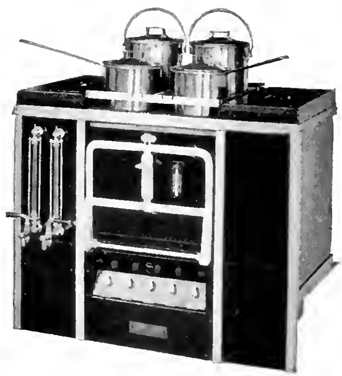


Fig. 80. Electric Range Made Up in Sections

as 12 by 16 feet at 100-foot throw. In order to secure high brilliancy the filament of the lamp operates at a temperature which gives an operating life of about 100 hours.

The lamp has been standardized in two sizes, one consuming 750 watts, at 30 amperes,

* Motion Picture Projection with Tungsten Filament Lamps, J. T. Caldwell, A. R. Dennington, J. A. Orange, L. C. Porter—presented before the Illuminating Engineering Society, December 13, 1917.

25 volts, and the other consuming 600 watts, at 20 amperes and 30 volts. With approved optical equipment they give a picture corresponding approximately to that obtained from the 40-ampere direct current arc.

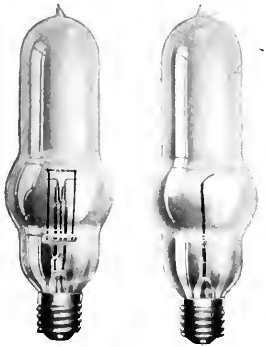


Fig. 81. 30-amp. Edison Mazda C Lamp for Motion Picture Projection

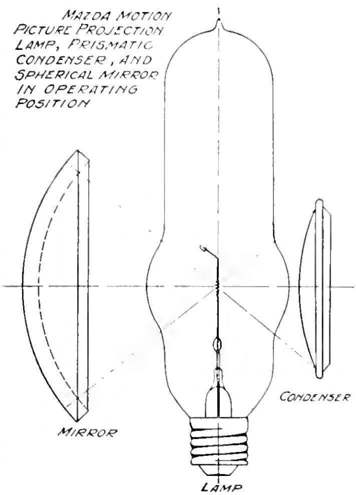


Fig. 83. Diagram of Optical System

Neither of these lamps is intended for large theaters where the more powerful high-current arcs provide a more suitable light source. For the more numerous class of smaller theaters, however, the incandescent lamp is well suited, economical, convenient and safe.

The leading moving picture machine manufacturers have not only designed lanterns for

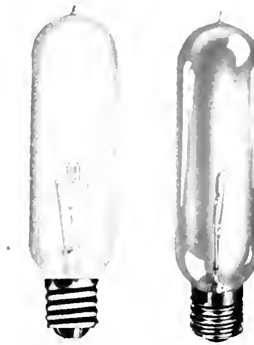


Fig. 82. 20-amp. Edison Mazda C Lamp for Motion Picture Projection

use with these lamps, but are also marketing parts for converting existing machines.

During 1916 a blue bulb incandescent lamp (Mazda C-2) was announced. The purpose of this was to provide a practical light for color selection, to meet usual requirements. While the light is not recommended for the most exacting work, such as is required in textile dye houses, for which condition a greater sacrifice in efficiency would have to be made, this lamp, which meets all ordinary requirements, has become quite popular and is meeting a large demand for the illumination of stores and many manufacturing processes involving color discrimination. Besides the obvious applications it has been utilized in the separation of ores on concentrating tables of large smelters, the matching of artificial teeth, distinguishing tissues in surgical operations, the inspection of X-ray negatives and color determinations in chemical processes. The lamps are made in the following wattages: 75, 100, 150, 200, 300, and 500 for 110/125-volt multiple service.

The total sales of tungsten filament lamps in the United States, excluding miniature lamps, for the year 1917, aggregated in round numbers 165 millions (Fig. 84), an increase over the previous year of about 14 per cent. The total number of miniature lamps sold was 75 millions (Fig. 85), an increase of about 40 per cent over the previous year.

The relative importance of lamps having a carbon filament, i.e., the carbon and Gem lamps, has decreased each year, so that at present it is about 12 per cent of the total, whereas ten years ago it was 100 per cent; at that time practically no Gem nor tungsten filament lamps were sold, as shown by the curve (Fig. 84).

The average candle-power of lamps for standard lighting increased from about 18 in 1907 to about 48 during the past year.

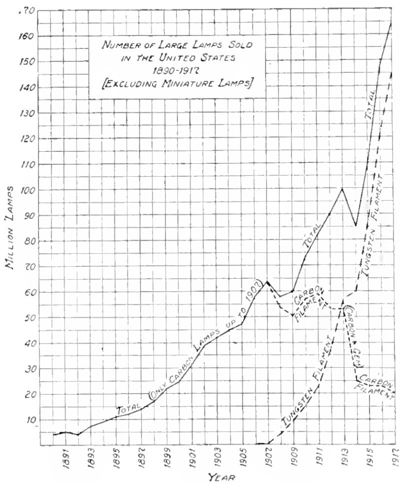


Fig. 84. Chart of Sales of Large Incandescent Lamps

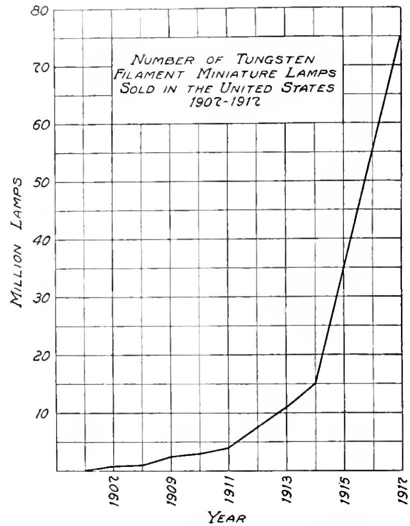


Fig. 85. Chart of Sales of Miniature Tungsten Lamps

The average wattage of lamps in 1907 was a little over 52 watts, coming down to a little under 48 watts in 1913, and during the past year was slightly in excess of 48 watts. This small increase in wattage in recent years is undoubtedly due to the increasing sales of the higher wattage non-vacuum tungsten filament lamps, which were put on the market in 1914. The result has been that the consumer has obtained over 200 per cent more light for a given cost than was obtainable ten years ago. This is determined by dividing the average wattage by the average candle-power of all lamps sold, and is considered as an actual increased amount of light for the same cost on account of the fact that the average wattage of the lamps has not increased during that period.

It is also interesting to note that the average candle-power of incandescent lamps used in street lighting has materially increased during the last ten years from 35 candle-power in 1907 to about 160 candle-power in 1917. Some of this increase is due to the displacing of carbon arc lamps by high candle-power tungsten filament lamps. Eliminating these units, the average candle-power was about 70 during the past year, or double that of ten years ago.

The sales of carbon miniature lamps have never become a big item, the maximum number in any year probably not exceeding two million lamps, and their sales last year probably not over half a million.

The sales of tungsten filament miniature lamps, however, since their introduction in 1907, has increased by leaps and bounds to about 75 millions sold during the past year. The majority of these lamps are used for flashlights and automobiles, but a considerable number are also used for candelabra and decorative lighting.

Many factories were operated day and night, in which previous to 1917 night work had been unusual, with the result that plants which had formerly required artificial light for an average of about two hours per day, demanded at least 14 hours. Besides increasing the lamp consumption on account of the extended hours of lighting, this feature also rendered necessary a better standard of illumination. The growth of high-speed production, combined with a greater appreciation of the importance of good illumination, all acted to increase the number of lamps used in industrial lighting.

A year ago it was stated that the Industrial Commissions of Pennsylvania and New Jersey had adopted rules for better lighting. At the present time, commissions in New York, Wisconsin, and Ohio are preparing similar regulations.

The measurement of illumination and, therefore, the enforcement of lighting codes, has been facilitated by the development of a compact, low cost, direct reading "foot-candle meter"* which is somewhat more simple to operate than the instruments previously available.

The foot-candle meter employs the same principle as the Bunsen or Leeson photometer screens. It can be illustrated by rendering a spot in a sheet of opaque paper trans-

Fig. 86. Foot-candle Meter—Front View

lucent with oil or grease. If then the sheet is lighted on one side only, the grease spot will appear darker than the rest of the sheet when viewed from the lighted side, and lighter when viewed from the unlighted side. When both sides of the sheet are lighted equally, the grease spot will disappear, being of the same brightness as the rest of the sheet.

As applied in the foot-candle meter, the effect of a series of such spots is secured by

Fig. 87. Foot-candle Meter—Rear View

mounting a strip of translucent paper on a strip of glass, and over it a corresponding strip of opaque paper in which small holes are punched, as shown in Fig. 86. This forms the cover of a long narrow box in which an incandescent lamp is placed at one end, so as to illuminate the underside of the strips. It is evident that the spots near the lamp will receive more light than those farther away. The exposed side of the strip is lighted uniformly by the illumination to be measured. Thus the spots at one end (the right) will appear brighter than the surrounding paper, while at the other end they will be darker. Between these extremes will be found a point at which the spots blend with the card and disappear, showing that the same intensity of light is falling on both sides. The scale figure, opposite this point, gives this intensity as determined by calibration and, therefore, indicates the illumination measured. Thus the illumination can be read in foot-candles at a glance.

In order to get correct results it is necessary that the incandescent lamp be operated at proper voltage, and this is made possible

* The Foot-candle Meter, C. F. Sackwitz, presented before the Illuminating Engineering Society, December 14, 1917.

by means of a rheostat and voltmeter, the current being supplied by a dry cell. (Fig. 87.)

The voltmeter registers the voltage supplied to the lamp, and as long as the voltmeter needle is directly over the arrow on the voltmeter scale, the lamp is operating at the correct voltage to supply the proper illumination to the photometric screen.

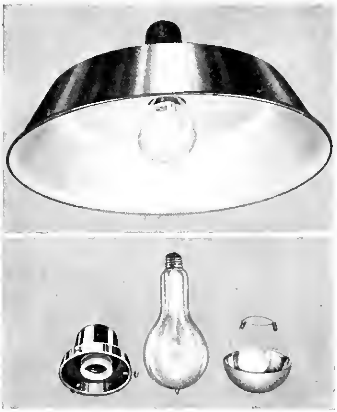


Fig. 88. Reflecto-cap Diffuser

An interesting development in street lighting practice was the use of a phantom circuit remote control, by means of which street lighting systems at a considerable distance from the central station can be connected direct to 2300-volt feeders, without running wires for special systems, and the station operator can control the various systems at will. This method obviates the necessity previously existing for manual operation of the distant lighting circuit switches or the use of time switches mounted on the pole with the transformer which supplies the lighting circuit.

The designation "phantom circuit"* is used because no separate circuit is required for the control, the impulse for operating the switch being sent over the feeder wires. Its operation is based on the well known fact that a circuit can be used for more than one purpose at the same time, and in this case the alternating-current power lines are utilized for the transmission of a small direct current without interferring with their normal function of carrying power. The high voltage lines are used as one side of the direct current circuit and the ground as the other.

The use of reactance permits the passage of the direct current, while the amount of alternating current which passes during the few seconds required to operate the switch by means of the direct-current phantom circuit is practically negligible.

Partly on account of the need for better industrial lighting and partly because of the increased use of Mazda C (gas-filled) lamps, with their more brilliant filaments, there arose a demand for better diffusing devices in industrial lighting. For most purposes

* See articles in G-E Review, by A. H. Davis, Feb., 1917 and H. H. Reeves, Nov., 1917.

Fig. 89. Novalux Fixture Pendant Unventilated Type with Stippled Globe and Dome Refractor

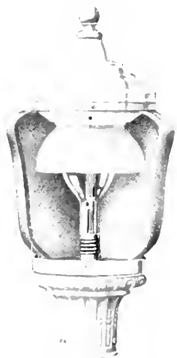


Fig. 90. Ornamental Novalux Unit with Eight-paneled Globe, Stippled Glass with Reflector and Refractor

Fig. 91. Ornamental Novalux Unit, Three-paneled Globe, Stippled Glass with Reflector and Refractor

this was met by the use of bowl-frosted lamps. Tests made with acid etched frosting, under rather severe conditions, showed that the loss of light due to the accumulation of dust and oil, was not much greater than with clear lamps, and cleaning was easily effected.

To meet the conditions where a still higher degree of diffusion seemed desirable, a new type of diffuser* was developed for the 100- to 300-watt lamps. With this equipment, the lower part of the lamp is concealed by a metal reflector (Fig. 88). The main reflector above the lamp is of large diameter, so that cross rays of light tend to soften the shadows.

A number of new street lighting units were also developed and three typical arrangements are shown.

The pendent type (Fig. 89) has a stippled glass globe and dome refractor.† The globe is made of clear glass which has a rough surface on the inside that diffuses the light with very little more absorption than takes place in the clear glass. The dome refractor collects the upward light and redirects it to the street surface at an angle of about ten degrees below the horizontal.

The ornamental unit (Fig. 90) has a globe consisting of eight panels of stippled glass inside of which is a dome refractor, and a similar arrangement utilizing a three-section globe of stippled glass inside of which is a dome refractor is shown in Fig. 91.

There was developed and standardized a complete new line of flood lighting projectors, making use of both aluminum and glass reflectors.

The glass forms are silver plated and then a copper plating is deposited by an electrolytic process over the silver plating. This

Fig. 92. Floodlighting Projector for Use with 1000-watt Mazda Lamp

hermetically seals the silvering and also acts as a protection to the glass.

Several different types of reflectors are used for different classes of work and for various sizes of lamps. A recent type is the so-called L-12 projector (Fig. 92), which is designed to make use of a regular 1000-watt multiple Mazda lamp. The particular field for this projector is large area lighting.

Fig. 93. Factory Yard Flood Lighted for Night Protection by One G-E Floodlighting Projector Equipped with 400-watt Edison Mazda "C" Floodlighting Lamp

Fig 94. Docks Illuminated for Night Protection by G-E Floodlighting Projectors

* Effective Lighting of Factories as Judged by Daylight Standards, Ward Harrison, Transactions-Illuminating Engineering Society, November 20, 1917.

† A Combination of Refractor and Diffusing Globe for Street Lighting, Ward Harrison, Transactions-Illuminating Engineering Society, October 10, 1917.

Previous to our participation in the war, floodlighting was receiving wide application for decorative lighting effects, which reached a climax in the lighting of the Capitol Dome at Washington (Fig. 95), for the inauguration of President Wilson.

The war, after creating a demand for flag lighting, has had a decided tendency to restrict the less utilitarian applications; on the other hand, floodlighting equipments have proved of great value to the government and to various industries, railways, etc., in providing an effective means of protective lighting (Figs. 93 and 94), whereby intruders may be detected and prevented from harming mines, oil wells, pipe lines, factories, bridges, piers, shipyards, railroad and storage yards, water supply systems, public buildings, etc. This, together with night construction work, resulted in a very sudden and severe demand for lamps and reflectors.

It must not be inferred from this that all protective lighting has employed floodlighting equipment, as street fixtures and ordinary enameled street reflector equipments have been used to fully as great an extent.

Fig. 95. Distant Night View of the Capitol at Washington, Illuminated by Floodlighting Projectors

Extinguishing Fires in Large Totally Enclosed Generators and Motors

By M. A. Savage

Alternating Current Turbo-Generator Engineering Department, General Electric Company

This article recommends the use of steam for extinguishing fires in windings of large motors and generators where the construction permits of its application. The results of tests show that steam is quite as effective as other substances, such as carbon tetrachloride and carbon dioxide, and is free from their objectionable features.—Editor.

Fires in electrical apparatus should properly be divided into two classes:

First, Those which occur in open apparatus. This should be subdivided into rotating and stationary.

Second, Semi-enclosed or completely enclosed apparatus, subdivided into rotating and stationary.

It is the completely enclosed rotating machine with which this article deals, notably that of the turbine type. These machines are necessarily very compactly built and are subject to enormous blower action. Fires in this class of apparatus, therefore, become very serious, and due to the blower action are more difficult to extinguish. Extinguishing of such fires has for some time past claimed the attention of some few operators. That the subject has not received the serious consideration of those most interested is evidenced by the number of machines, the windings of which have been completely destroyed by fire. Thousands of dollars are thus lost each year, while still larger amounts are lost by the imposed idleness of the whole unit while the windings are being repaired.

A series of tests have recently been conducted by the General Electric Company to determine the best method of putting out such fires. Fig. 1 shows the test apparatus, which consists of a sheet iron cabinet, four feet cube. To this was attached a 12-in. pipe which connected the cabinet with a motor-driven fan for supplying the necessary draft. Both the inlet and outlet ducts were provided with quick closing dampers. The cabinet was filled with a number of scrap coils and waste material, and this was ignited with a gas jet. The fan was next started and made to deliver a known volume of air. When the combustion had reached a given stage, as determined by the eye, the outlet damper was closed and steam admitted to the cabinet. Fig. 2 shows the steam issuing from the inlet to the blower after having overcome the pressure of the air. This gives visual evidence that the cabinet and connecting duct were completely filled with steam. The experiment was repeated with the inlet damper closed.

Fig. 1. Apparatus for Making Tests

Fig. 2. Showing Steam Issuing from Blower Inlet, Against Air Pressure

In all of these experiments conditions were maintained such as to represent those which exist in an actual machine. The volume and pressure of air, the leakage air, etc., were apportioned to represent say a 25,000-kw. machine.

The following table gives the result of this test.

TABLE I

Cu. Ft. in Cabinet	Cu. Ft. of Air Per Minute	Pressure Inches of Water	Leakage Air with Damper Closed	Steam No. Min.	Time Required to Put out Fire
64	1250	1	500	25	*30 seconds

* The blaze was extinguished almost instantaneously, but it was found necessary to leave the steam on for 20 or 30 seconds to thoroughly wet the outer surface of coils so that charred portions would not again ignite.

Other experiments were made with carbon tetrachloride and carbon dioxide in the same manner.

The results of these tests would seem to indicate that for this class of apparatus, steam, if supplied in sufficient quantities, will put out any fire which may occur by burning insulation. Further, that the insulation when properly dired out after its steam bath, will not be materially damaged.

Carbon tetrachloride, while not as effective as steam, will put out such fires if used in sufficient quantities. It has the disadvantage, however, that it will attack and destroy the insulation; second, the fumes as given off by carbon tetrachloride are very injurious when breathed.

Carbon dioxide seems to be equally effective in putting out such fires, but it has the drawback of being hard to apply. It has to be kept in containers under very high pressure and there are instances where the heat absorbed by the release of these gases would quickly "freeze up" the outlet nozzle.

Time the Main Factor in Putting out Fires

It cannot be too strongly brought out that the main factor in putting out any fire, with any extinguisher, is time. Just as it is useless for the fireman to play a stream of water on a building after it is completely destroyed, so it is equally useless for an operator to expect to find his windings intact after a fire has been burning an appreciable time. The sooner this fact is permanently fixed in the minds of those persons operating machines the easier it will be to deal with such fires. If the operator is willing to go into the subject systematically and make a thorough study of the exact conditions, the extinguishing of such fires should not be a matter of serious difficulty.

There are a few essential principles, which are here set forth:

First, the machine should be disconnected from the line and have its excitation removed. This should preferably be done automatically, thereby eliminating waste of time and the human element.

Second, the dampers with which the machine should be provided should close quickly and tightly. It is essential that the leakage be not too great or thus the volume of steam required will become prohibitive. It is not enough to determine this leakage by merely feeling the amount of air escaping—this should be accurately measured. A leakage of from say 10 to 20 per cent may be reasonable. These dampers should receive frequent inspections to see that they close properly, that no dirt collects in them in such a manner as to prevent their closing, and that the operating mechanism has not rusted to such a degree as to make smooth and efficient closing impossible.

Third, the steam should be readily available so that no time will be lost in getting it into the generator. If a coupling is to be made to connect to the steam supply this should be designed so as to require as few operations as possible.

Volume of Steam

The volume of steam which will be required for the various size machines may be determined from the cubic feet of air space in the machine, allowing one pound per minute for each 2.5 cubic feet of enclosed area, provided the leakage does not exceed ten per cent. If the leakage exceeds ten per cent the amount of steam should be approximately one pound per minute for each 20 cubic feet of leakage air. In a 25,000-kw., 60-cycle machine of 1800 r.p.m. this will amount to approximately 600 lbs. of steam per minute on a basis of 20 per cent leakage air. The area in square inches of nozzle openings to give this amount of steam per minute may be found from Napier's formula:

$$\frac{PA}{1.166}$$ Where P = Absolute pressure

A = Area of orifice in sq.inches.

On the 25,000-kw. machine referred to, this would amount to about 2.32 sq. in. orifice for each end of the generator. This is on a basis of 150 lbs. absolute steam pressure.

This amount of steam might be carried from the turbine to the generator end by a $3\frac{1}{2}$-in. pipe.

Location of Steam Pipes

The best location of steam inlets is on the inner shield so that numerous jets will impinge directly on the end portion of the winding and will be carried through the generator by the action of the fan. (See location A, Fig. 3). The inlets may be located in the air inlet duct (see location B, Fig. 3), but in this position they are not quite as effective, as the time required to expel the air from danger spaces will be slightly longer.

Location of Dampers

It has been found by experience that a damper located in the air exhaust duct proves much more effective than in the inlet duct. The closing of the inlet duct, however, will prove effective, provided a slightly larger volume of steam is allowed for than that given above.

It is not recommended that both the outlet and inlet ducts be closed at the same time, as the pressure which might be built up by the steam might cause injury to the generator. This difficulty may be overcome by the use of dampers which are held shut by springs which would release when the pressure reached a dangerous value. Such devices, however, would only complicate the mechanism.

Secondary Advantage in the Use of Steam

When a large unit which has been running at practically full load has its load suddenly thrown off the control of the steam becomes quite a serious problem. Any steam, therefore, which can be utilized will materially aid the fire room force in keeping the pressure down below the danger point.

Use of Water

Water has long been considered the best agent for extinguishing fires. Its use, however, in completely enclosed apparatus, is attendant with some uncertainty both as regards its application and also its effect on the rotating parts. No data are available as to its use for this purpose.

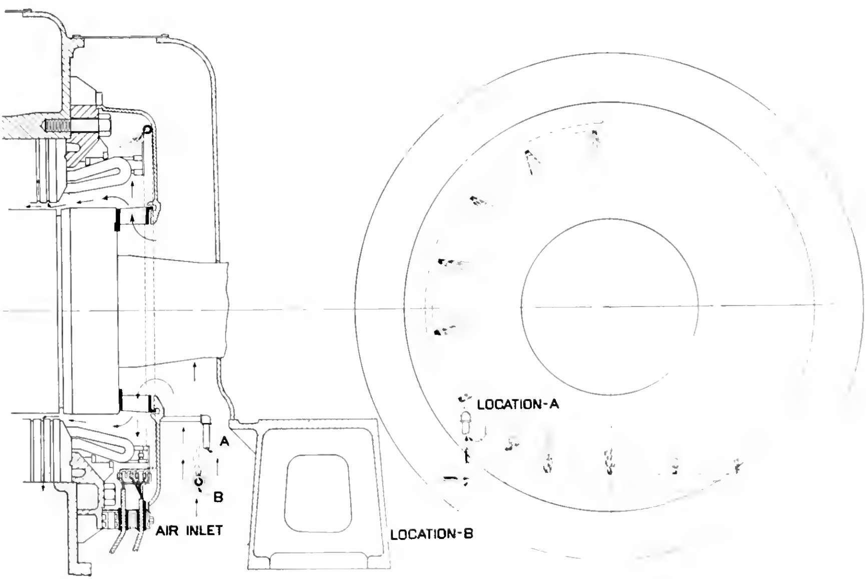


Fig. 3. Diagram showing Suggested Arrangements of Steam Jets

A New Radiator Type of Hot-cathode Roentgen-ray Tube

By Dr. W. D. Coolidge

Research Laboratory, General Electric Company

The following article is descriptive of the new radiator type of hot-cathode Roentgen-ray tube, developed for military use. The essential feature of this tube is the target of large heat capacity (provided with an external radiator) of such composition that the focal spot will not at any temperature emit electrons. The tube, therefore, is self-rectifying, which fact makes it feasible to operate the tube directly from the terminals of a high-tension transformer. A description of a simple and effective lead-glass protective shield is included. —Editor.

INTRODUCTION

The type of tube described in this article was developed specifically for military use in the portable Roentgen-ray outfits at the Front. Its characteristics are such, however, that it seems ultimately destined to supplant the earlier type of hot-cathode tube for all diagnostic work.

THE PROBLEM

A study of the situation had shown that the electrical efficiency of existing portable Roentgen-ray generating outfits was low,[1] and that it could be very greatly increased if a suitable tube could be developed for operation directly from the secondary of a high-tension transformer, without the use of any auxiliary rectifying device. As the portable apparatus was intended for diagnostic work, it was highly desirable that the focal spot in such a tube should be as small as possible for handling the required amount of energy.

THE STATUS OF THE PRIOR ART

The earlier form of hot-cathode tube having a solid tungsten target is capable of rectifying its own current; but only for such amounts of energy as do not heat the focal spot to a temperature approximating that of the cathode spiral. As soon, however, as any part of the focal spot is heated to a sufficiently high temperature, it emits electrons copiously, and, therefore, when supplied from a source of alternating potential, it permits so-called "inverse" current to pass. The "inverse" cathode-ray stream comes out from the focal spot in a direction perpendicular to the face of the target and proceeds, in the form of a narrow pencil, straight to the glass wall of the bulb close to and slightly behind the cathode. The glass at this spot fluoresces vigorously, becomes locally heated, and usually cracks. As air enters the bulb, a spark discharge passes through the opening and it is then easy, for one who has not studied the phenomenon, to conclude that the tube failed by puncturing under electrostatic strain.

The local heating of the glass, attendant upon overloading a tube which is running on alternating current, can be prevented by making the cathode focusing device of some refractory metal, such as molybdenum or tungsten, and so locating this in the tube that it intercepts the "inverse" cathode-ray stream.[2]

While this method has proved exceedingly useful as a safety device when such a tube is to be used on alternating current, it does not appreciably increase its capacity, for it would obviously be undesirable to have the cathode focusing-device giving off Roentgen-rays under such bombardment.

The essential condition to be fulfilled was that heat should be more rapidly withdrawn from the focal spot. This could have been accomplished by water-cooling,[3] but this method clearly involved undesirable complications for portable work. Experiment showed that the most effective simple method consisted in providing a target having a large heat capacity and high heat conductivity, and then in arranging to effectively cool this mass of metal during the interval between radiographic exposures. The importance of having the target cold at the start is shown by the following experience with a tube having a 3.2 mm. focal spot and a solid tungsten target: With the maximum allowable energy input, it was possible when beginning with the target at room temperature to run four times as long before "inverse" current appeared as when the experiment was started with the target at dull red heat

Now in the case of the ordinary Roentgen-ray tube, the cooling of the target from dull red heat to room temperature is an exceedingly slow operation. The heat can get out only (*1*) by radiation, which, with small differences in temperature between the hot body and its surroundings, takes place at a very low rate, and (2) by conduction through the small lead-in wire and through the glass.

DESCRIPTION OF THE RADIATOR TYPE OF TUBE

The Anode

The considerations which have been described finally led to the anode design shown in Fig. 1. The anode stem consists of a solid bar of copper 1.6 (5/8 in.) in diameter which is brought out through the glass of the anode arm to a copper radiator. The head of the anode consists of a mass of specially purified copper which is first cast in vacuum onto a tungsten button and is then electrically welded to the stem. The tungsten button, which is destined to receive the cathode ray bombardment is 2.5 mm. (0.1 in.) thick and 9.5 mm. (3/8 in.) in diameter.

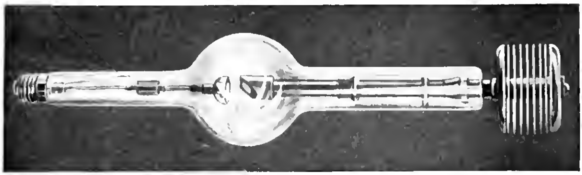


Fig. 1. Special Self-rectifying Roentgen-ray Tube

The complete target, with radiator, weighs 860 gm. and has a heat capacity of 81 calories per degree Centigrade; while the present standard solid tungsten target, complete with molybdenum stem and iron supporting tube, has a heat capacity of less than 10 calories. Because of its greater heat capacity, it takes much longer to heat the radiator type of target to a given temperature than it does the solid tungsten target. What is much more important, however, is the fact that between radiographic exposures the target in the new tube cools comparatively rapidly owing to the large copper stem and the radiator.

The Cathode

The cathode in this tube has been designed to give a focal spot 3.2 mm. (1/8 in.) in diameter with a very uniform energy distribution.[4]

Size of Bulb

In the standard hot-cathode tube with the solid tungsten target, the target gets very hot and radiates through the glass walls of the tube the greater part of the energy it receives. As a result, the glass becomes strongly heated. In the new radiator type of tube, by far the greatest part of the energy imparted to the target is conducted to the radiator. It, therefore, becomes possible to make the glass bulb very small. For portable work, a diameter of 9.5 cm. (3¾ in.) has been standardized.

The Exhausting of the Tube

The exhausting of a hot-cathode tube, containing the anode which has been described, to such a point that the tube could be sealed off from the pump appeared at first to be an impossibility. A point was finally reached where after sealing the tube off and allowing it to stand overnight, the vacuum was good. Upon operating such a tube for a few seconds, however, the vacuum rapidly deteriorated until the tube showed a Geissler glow. After a second exhausting, covering a period of several hours, the experience mentioned was duplicated with this difference: the tube operated successfully for a somewhat longer time. A third exhausting, again extending over a period of several hours, finally resulted in a good tube. Since that time it has developed that the exhaust is made much easier by first filling the tube with purified hydrogen and then heating it strongly. It is still a very serious operation, however, when compared with even the exhausting of the hot-cathode tubes of the earlier type.

THEORY OF OPERATION

In the radiator type of tube, the passage of "inverse" current is avoided by a construction which removes heat from the focal spot so rapidly that, in normal use, it never reaches the temperature at which an appreciable thermionic emission of electrons can take place. In testing the first tubes of this type, it was found that some other very powerful cause was acting to prevent electron emission from the focal spot. It developed that, in this tube, the temperature of the focal spot could be raised to that of the cathode spiral and even brought to the melting point, while the tube was operating on alternating current, without having the tube allow any appreciable "inverse" current to pass.

The most probable explanation of this phenomenon appears to be as follows: The thermionic emission of electrons from a heated tungsten surface is very greatly reduced by traces of oxygen. Now in the case of the solid tungsten target, the oxygen which is originally present in the metal is removed during the exhausting of the tube by maintaining the target for a considerable time at intense white heat while the tube is connected to the pump. Under these conditions oxide of tungsten dissociates, and the oxygen is removed from the tube by the pump. In the radiator type of tube the conditions are very different. There is, at the beginning of the exhausting process, a large amount of oxygen both in the tungsten button and in the copper of the target. During the exhausting, the temperature of the target must at all times be kept below the melting point of copper. As a result, there is probably sufficient oxygen left in the target to account for the observed phenomenon. The oxygen in the tungsten at the focal spot would be liberated by the heat produced by cathode ray bombardment. This oxygen would then be chemically removed from the surrounding space by the hot copper of the target. Other oxygen in the metal layers just behind the focal spot would then diffuse to the focal spot; and this cycle of operations would go on indefinitely, the trace of oxygen in the tungsten at the focal spot always greatly reducing the electron emission.

With a tube containing such a target, heat is conducted away from the focal spot so rapidly that the tube could satisfactorily be used to do the work for which it was intended without the help of the phenomenon mentioned. The latter furnishes a factor, however, which strongly safeguards this type of tube when rectifying its own current.

OVERLOAD LIMITATIONS AND BEHAVIOR OF THIS FIRST MODEL OF THE RADIATOR TYPE TUBE

The first model of the radiator type tube was designed to carry 10 milliamperes at a 5-in. parallel spark between pointed electrodes for the time required for making the most difficult radiographs, and to carry a fluoroscopic load of 5 milliamperes at a 5-in. parallel spark continuously for an indefinite period.

Under abuse, its behavior is as follows: When operated continuously with 10 milliamperes at a 5-in. parallel spark and with a constant heating current in the filament spiral, the milliamperage may gradually drop. If the experiment is continued until the anode is red hot, and this will take about 2½ minutes, the current may drop to as low as 6 milliamperes. (The amount of this drop depends upon the degree of the exhaustion, being greater the poorer this is.) Upon cooling the anode, the vacuum immediately returns to its original condition, as shown by the fact that, with the same filament current, the milliamperage returns to 10. It is surprising to see how quick this recovery is; it has been found to take place even in the short time that it takes to cool the anode by holding the radiator under a cold-water faucet. This recovery is doubtlessly due to gas absorption by the anode.

MEASUREMENT OF VOLTAGE WITH TUBE RECTIFYING ITS OWN CURRENT

Upon operating a tube, which rectifies its own current, directly from the secondary of a transformer, the "inverse" voltage is always higher than the "useful" voltage. Consequently, the measurement of tube voltage by a parallel spark-gap used in the ordinary way would, in general, be very misleading, for the observed spark length corresponds to the "inverse" voltage and not to that which produces the Roentgen-rays and hence determines their nature. A simple and very satisfactory method of dealing with this difficulty consists in connecting an alternating-current voltmeter across the primary of the transformer and then calibrating once for all this combination of transformer and voltmeter. The calibration can be conveniently made with the help of a kenotron connected in series with the Roentgen-ray tube. The two tubes should be so connected that current can pass through the Roentgen-ray tube in the right direction. If now a spark-gap is connected across the Roentgen-ray tube terminals, it measures the useful voltage (and this is essentially what it would be if the kenotron were not in the circuit, for the voltage drop in a suitable kenotron is not more than one or two hundred volts and can hence be neglected). If the spark-gap were connected directly across the transformer terminals it would measure the "inverse" voltage. The difference between the two will depend upon the load and hence it is necessary that the calibration should be made for every load which it is desired to use with the tube. Unless appreciable changes take place in the wave form of the current supply, a single calibration suffices, and this can be made by the manufacturer of the transformer. Unless otherwise specified, the voltage referred to in this article is always the "useful" and not the "inverse" voltage.

ATTACHMENT OF RADIATOR TO TARGET STEM

In the first radiator type tubes made, the radiator was soft-soldered to the copper stem of the target. It was later found that the tube would stand almost as hard abuse if the solder was omitted and the radiator was simply slipped on over the stem and held in place by a thumb-screw. This has made it possible, for some applications, to adapt a simple close-fitting two-part lead-glass shield to the tube.

LEAD-GLASS PROTECTIVE SHIELD

As such a shield is, in some cases, a matter of considerable importance, it is perhaps well to discuss briefly a form which seems very satisfactory. It is evident that there will be some applications where the tube shield ought, for a given amount of protection, to be as light as possible. In these cases, it should obviously have the same form as the tube and should fit closely to the latter. Furthermore, it should let the heat energy of the cathode-spiral radiate through it, as otherwise both the shield and the tube would, with prolonged filament excitation, get very hot. The ideal light-weight shield will then be a non-conductor of electricity, to permit of its being closely fitted to the tube, and will be transparent to ordinary light radiations. Glass containing sufficient lead would be a satisfactory material from which to make such a shield. The ordinary X-ray protective glass with which the author is familiar does not have as high a lead content as seems desirable. The best samples which he has tested have to be used in layers 10 to 12 times as thick as metallic lead to give the same protection as the latter. Experiments made by Dr. G. Stanley Meikle of this laboratory showed that glass could be made experimentally which contained so much lead that, for the same protective effect, the glass layer had to be only 1.4 times as thick as sheet lead. Such glass when melted attacks the glass-pot quite readily and may, therefore, be difficult to manufacture. However, the author has recently been able to obtain glass* containing enough lead that, for the same protective effect, the glass layer has to be but 4 times as thick as sheet lead.

The properties of this glass are such that it cannot be readily blown into thick-walled bulbs, but it can be pressed in moulds. Fig. 2 shows a picture of a tube surrounded by such a shield which is made in two parts bolted together in the middle. A hole in one side permits egress to the desired bundle of Roentgen-rays.

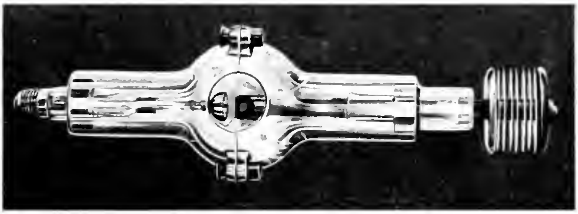


Fig. 2. Tube in Lead-Glass Shell

APPLICATIONS OF THE TUBE

Two portable Roentgen-ray generating units have already been built around the first model of this tube. These are the "U.S. Army Portable Unit" and the "U.S. Army Bedside Unit." In both of these outfits, the tube is operated directly from a high-voltage transformer with no auxiliary rectifying device.

This model of the tube should also be useful for general fluoroscopic work and for all radiographic work which can be done with a focal spot as small as 3.2 mm. (1/8 in.) in diameter. (This means an amount of energy not in excess of that corresponding to 10 m.a. at a 5-in. parallel spark between pointed electrodes.)

For more rapid radiography, other models will be developed with larger focal spots, but

* From the *Corning Glass Works.*

probably with the same external tube dimensions.

ADVANTAGES OF THE RADIATOR TYPE TUBE

The advantages which the new type of tube possesses over the earlier type for diagnostic work are the following:

(1) It can be used to rectify its own current under conditions of service which are much severer than would be permissible with the earlier type of hot-cathode tube having the same size of focal spot.

(2) The bulb can be smaller than is permissible with the earlier type handling the same amount of energy.

(3) On either alternating- or rectified-current it will carry the maximum allowable energy for a much longer time.

(4) It can have, even for heavy duty, a close-fitting tube shield.

The author desires to express his thanks to George Hotaling, C. N. Moore, and Leonard Dempster for their assistance in carrying out the work which has been described.

[1] The electrical efficiency of Roentgen-ray apparatus has usually been comparatively unimportant, but as efficiency determines the weight and bulk of the entire generating outfit, it is obviously a very important factor in the design of portable outfits.

[2] Under these circumstances, the fact that the tube is being overloaded is shown by a sudden vigorous local heating of the focusing device. In case the area heated in this way becomes sufficiently hot, it becomes a third source of cathode rays. These last cathode rays focus on the target at a point somewhat removed from the original and legitimate focal spot. This can be very easily observed and confirmed by the pinhole-camera method.

[3] Coolidge, Am. J., of Roentgenology, pp. 7–8 (1915).

[4] For the method of developing a suitable cathode design, see American Journal of Roentgenology, pp. 5–6 (1917).

[5] I. Langmuir, Phys. Rev. pp. 465–466 (1913).

A Portable Roentgen-ray Generating Outfit

By W. D. Coolidge and C. N. Moore

Research Laboratory, General Electric Company

The following article is descriptive of the development of a complete portable Roentgen-ray generating outfit for military service in the field. The essential features of the resulting unit are its simplicity, compactness, portability and unusually high efficiency. Seventy per cent of the generated energy is utilized in the generation of Roentgen-rays. The tube has been especially developed for use in this outfit and is fully explained on page 56.—Editor.

INTRODUCTION

When it appeared that this country might become involved in the European war various Red Cross Units were formed, and some of these instituted inquiries concerning Roentgen-ray apparatus suitable for war needs. It was through such inquiries that the authors became interested in the problem of a portable Roentgen-ray generating outfit.

The problem as it first presented itself appeared rather indefinite, as but little was generally known concerning the degree of portability required, the current and voltage needed to operate the tube, the amount of service which would be required of the apparatus, the question as to whether power could usually be had from existing electric circuits, etc.* Existing outfits apparently left much to be desired. The best way of attacking the problem seemed to be to investigate the various possible systems, so as to determine which was best adapted for development into a generating outfit of considerable portability and sufficient output.

* Among others, the following excellent papers bearing on the subject were read with great interest.

The X-ray equipment and work in the Army at the present time, by Capt. William A. Duncan, American Journal of Roentgenology, 268–275 (1914).

The Electrotechnical Problem of the Production of Roentgen-rays in the present War, by Dr. Umberto Magini, L'Electrotechnica, Vol. III, No. 7, March 5, pp. 126–133 (1916).

SYSTEMS INVESTIGATED

The various systems which the authors seriously considered for the purpose were:

(1) A gasolene-electric set furnishing low voltage direct current to a rotary converter, with a step-up transformer and a mechanical rectifier attached to the shaft of the rotary.

(2) A gasolene-electric set furnishing alternating current to a step-up transformer and with a mechanical rectifier driven from a small synchronous motor.

(3) The same as (2), except for the substitution of a kenotron for the synchronous motor and mechanical rectifier.

(4) A gasolene-electric set furnishing alternating current to a step-up transformer, with a self-rectifying Roentgen-ray tube operating directly from the latter.

(5) A storage battery operating an induction coil through a mechanical interrupter or a mercury-turbine interrupter with suitable gas dielectric.

(6) A storage battery operating a motor-generator and so producing alternating current to be fed to a step-up transformer and thence to a self-rectifying Roentgen-ray tube.

An investigation of these separate methods led to the elimination of all but (4) for the following reasons:

With (1), to avoid the use of long high-tension leads, it appeared necessary to locate the gasolene-electric set close to the Roentgen-ray table, and hence to make the operating room noisy. Furthermore, the efficiency of a small rotary is very low for the size in question, perhaps 25 per cent, and this would necessitate the use of a relatively large and heavy gasolene-electric set.

There were numerous objections to (2). It practically necessitated placing the rectifier near the operating table where the noise was undesirable; the use of the synchronously driven mechanical rectifier involved the loss of a considerable amount of energy (the small one which we tried consumed 350 watts); the behavior of this rectifier on the current supplied by a dynamo driven by a small single-cylinder, 4-cycle engine was not good; and finally, the rectifier looked like a serious complication provided it could be dispensed with.

While (3) was good, it was clearly not as simple as (4).

It developed that the electrical efficiency of both (5) and (6) was very low, probably less than 25 per cent. This meant that, for the production of any reasonable Roentgen-ray intensity for any considerable length of time, either of these systems would lead to a relatively heavy outfit.

THE SYSTEM CHOSEN

System (4), consisting of a gasolene-electric set furnishing alternating current to a step-up transformer, and with a special self-rectifying Roentgen-ray tube operating directly from the latter, was finally chosen. The advantages of this system when compared with the others may be briefly summarized as follows:

It is simpler.

It is more efficient electrically.

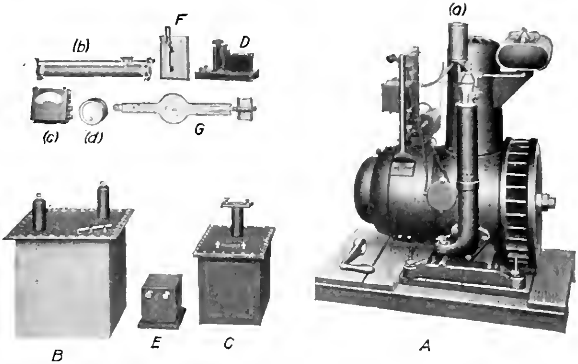


Fig. 1. Separate Units Comprising Portable Roentgen-ray Outfit

It is lighter in weight for a given output, and hence more portable.

It does not involve the care of a storage battery.

It involves the use of no moving parts other than the gasolene-electric set.

The outfit is self-contained, requiring merely gasolene to run it, and hence can be operated anywhere at any time regardless of the presence or absence of electric supply circuits.

The one member having moving parts, namely the gasolene-electric set, can be located at any desired distance from the Roentgen-ray room.

THE OUTFIT AS DEVELOPED

Separate Elements Comprising the Outfit

Having settled upon the system, it became necessary to get the component parts. The exigency of the case made it desirable to use, in so far as possible, apparatus which was already in production and hence readily available. For this reason, apparatus was borrowed from many different manufacturers and tested for its fitness for the particular purpose in question. The elements which were finally chosen are shown in Fig. 1. A description of each of these elements, together with the reasons for choosing it, is given in the following:

(*A*) *Gasolene-electric Set.*

Various single- and multiple-cylinder engines of the 2-cycle and 4-cycle type were tried out, and the conclusion was reached that the one which was best adapted to the purpose was the Delco-light engine made by the Domestic Engineering Company of Dayton, Ohio. This engine was already direct-connected to a dynamo.

Fig. 2. Special Self-rectifying Roentgen-ray Tube

The Delco-light set was originally built for direct current at 40 volts, but by a change in armature- and field-windings and by the addition of a pair of slip rings and brushes it was adapted to furnish alternating current at the desired voltage. The engine was also provided with a special throttle-governor for regulating the generator voltage. This governor consists of a solenoid (a) mounted above the carburetor, the movable core of the solenoid being connected to the butterfly valve of the throttle. The solenoid is operated by direct current taken from the commutator of the generator. A variable resistance (b) is placed in series with the solenoid, and by means of this resistance any throttle opening and hence any desired engine speed and alternating current voltage may be obtained. The alternating-current voltage is indicated by the voltmeter (c).

The reasons for choosing the Delco-light outfit in preference to others were:

- It has a single cylinder engine with corresponding mechanical simplicity.
- The engine is of the 4-cycle type and hence easy to start and flexible in operation.
- The engine is air-cooled, and this does away with the possibility of having water freeze in the jackets in cold weather.
- The armature of the dynamo is mounted directly on the crankshaft of the engine and the crankshaft has but two main bearings. This effectively does away with coupling troubles and with lack of alignment.
- It is self-lubricating.
- It is self-excited.
- It is of suitable capacity.
- It has been developed for long continued service with a minimum amount of attention.
- At great expense, it has been thoroughly standardized, and this means interchangeability of parts, and that all sets will have essentially the same characteristics.
- The workmanship is excellent.
- It is available in any desired quantity on very short notice.

(*B*) *Roentgen-ray Transformer.*

A small transformer, made by the Victor Electric Company of Chicago, for their dental radiographic outfit, was chosen for the following reasons:

- It is an oil-insulated closed-magnetic circuit transformer of the proper capacity.
- It is oil-tight.
- Its design is such that, with the load in question, the "inverse" voltage is not prohibitively high.
- It was available on short notice, as only two minor changes were required. These changes consisted in adapting the primary winding to the voltage of the generator and in bringing out leads for the milliammeter (d) from the grounded middle point of the secondary (this makes the milliammeter a low-tension instrument).

(*C*) *Filament-current Transformer.*

Here again it seemed imperative that an oil insulated transformer should be used, and that this should be electrically efficient, of light weight, and oil tight.

The Victor filament-current transformer appeared to fulfill these conditions better than any other which was available at the time.

(*D*) *Filament-current Control.*

That manufactured by the Wappler Electric Company was chosen for this outfit because of its small size, fineness of regulation, and the fact that the setting, once made, was not easily disturbed.

(*E*) *Booster.*

The line voltage drops considerably when the full load is thrown on the generator.

To prevent the lowering of the filament-current which would result from this, a small transformer was designed, the primary of which is inserted in the primary circuit of the X-ray transformer and the secondary in the primary circuit of the filament-transformer, as shown in the wiring diagram (Fig. 3).

(*F*) *Operating Switch.*

A single-pole single-throw switch of substantial construction was chosen.

(*G*) *Special Self-rectifying Tube.*

There was no tube suitable for diagnostic work and capable of rectifying its own current, for frequent long exposures, with as much energy as that available from the Delco-light set. It, therefore, became necessary to undertake its development, and the result is seen in Fig. 2. This tube is fully discussed in a separate paper published in the current number of the Review by one of the authors. Briefly, it is a hot-cathode tube with a 9.5 cm. (3¾ in.) bulb. The cathode has been especially designed to give a focal spot 3.2 mm. (⅛ in.) in diameter and with a very uniform distribution of energy. The target consists of a small wrought-tungsten button set in a solid block of copper, and this block is electrically welded to a solid copper stem 1.6 cm. (⅝ in.) in diameter which extends out through the anode arm to an external radiator. A platinum sleeve is silver-soldered at one end to the copper stem and attached at the other end to the glass of the anode arm. The target, complete with stem and radiator, weighs 860 gms. and has a heat capacity of 81 calories per degree centigrade. The present standard solid tungsten target, complete with molybdenum stem and iron supporting tube, has a heat capacity of less than 10 calories Because of its greater heat capacity, it takes much longer to heat the radiator type of target to redness than it does the solid tungsten target. Unlike the latter, the target in the new tube, even at relatively low temperatures, cools rapidly in the interval between radiographic exposures, and, therefore, permits of starting each exposure with an

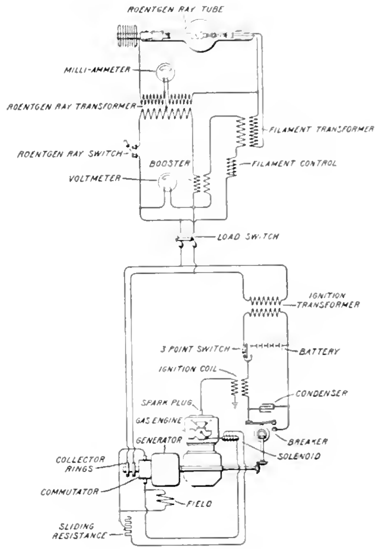


Fig. 3. Complete Wiring Diagram

essentially cold target. As a result the focal spot, even though small, is kept from reaching a temperature high enough to allow "inverse" current to pass through the tube. Furthermore (and this serves as an additional safeguard), this type of tube does not allow

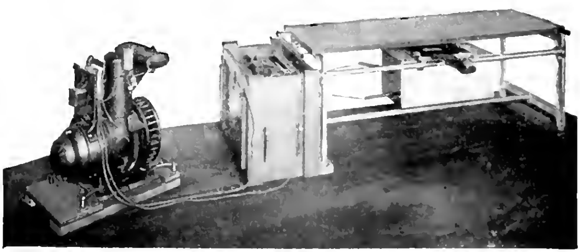


Fig. 4. Complete Portable Roentgen-ray Outfit

an appreciable amount of inverse current to pass even though it is so badly overloaded that the focal spot becomes heated to the melting point. A probable explanation of this striking fact is given in the companion article on the tube.

COMPLETE WIRING DIAGRAM

This is shown in Fig. 3. and needs no further explanation.

COMPLETE OUTFIT

The complete outfit is shown in Fig. 4, in which the gasolene-electric set is seen at the left. The Roentgen-ray and filament-current transformers, the filament current control, and the booster are in the lower part of the box at the end of the table (see Fig. 5, which shows the inside of this box). On a shelf in the top of this box are a voltmeter for showing line voltage, the adjustable rheostat for controlling line voltage, a milliammeter for indicating the tube current, and the operating switch. (There is a cover for this box which is screwed on for shipment.) The X-ray tube is permanently located in the movable tube-box under the table.*

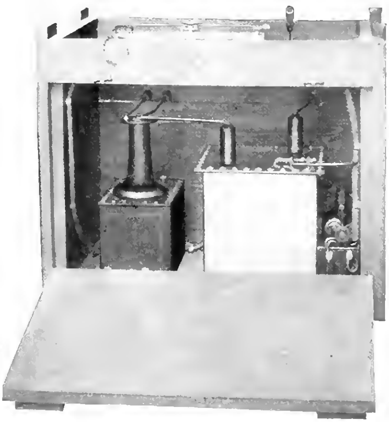


Fig. 5. Transformer and Instrument Box

TECHNIQUE

The outfit as described lends itself readily to a very simple technique. Experience extending over several years has convinced the writers that it is very convenient, for experimental work, to have extreme flexibility in a Roentgen-ray generating outfit, so that the penetrating power of the rays can be varied at will between wide limits. It has also convinced them, however, that Roentgenologists would get better average results in diagnostic work if their outfits were made much less flexible, so that the Roentgen-ray tube could be used more, for example, as the ordinary incandescent lamp is. When such a lamp is lighted on the ordinary constant-potential circuit, it gives always the same kind and the same amount of light. It is entirely practicable to operate a Roentgen-ray tube in this same manner. It is merely necessary to see that the filament current is always the same and that the high-tension voltage impressed upon the tube terminals is always the same. Under these circumstances the tube always gives out Roentgen-rays of the same penetrating power† and of the same intensity. More artistic radiographs can be made by adapting the penetrat-

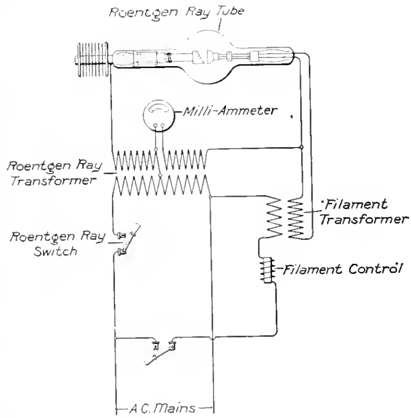


Fig. 6. Wiring Diagram for Outfit Operated Directly from Existing Alternating Current Mains (when Gasolene Electric Set is not needed)

* The table, tube box, and shutter were all developed by the co-operative work of others, including Major Shearer, Major Geo. Johnston, and the Kelley-Koett Company.

† These rays are not homogeneous, but the mixture is always the same.

ing power of the rays to the thickness of the part to be radiographed, but experience shows that with a suitable compromise voltage (we have adopted that corresponding to a 5-in. spark between pointed electrodes which is equal to 57,500 volts effective, as actually measured by a sphere gap) excellent radiographs can be made of all parts of the human body, and with a great simplification in apparatus and technique. The time factor becomes the only variable and this is adapted to the thickness of the part to be radiographed.

With 57,500 volts (effective) and 10 milliamperes and a distance of 45.7 cm. (18 in.) from focal spot to plate, the writers have found that for Seed plates and the average adult subject, the following table of exposures gives good results:

Exposures 18 in. distance

	Sec.		Sec.
Hand	1	Chest	10
Elbow	2	Hip	20
Ankle	2	Head-lateral	25
Knee	4	Frontal sinus	50
Shoulder	8		

Too much weight should not be attached to this table, as it is based on a relatively small amount of work. It is merely given to show in a general way how the time of exposure varies for different parts of the body when the intensity and penetrating power of the rays are held constant.

The compromise voltage used for radiography appears well suited to fluoroscopy, and at this voltage a current of 5 ma. appears to give sufficient illumination.

The reason for adopting for radiography the amount of energy corresponding to 10 ma. at a 5-in. spark was that it was the maximum amount available in the tube when operating from the Delco-light generator.

This energy could, of course, have been taken at any desired potential, as this was merely a matter of transformer design. The reasons for choosing the potential corresponding to a 5-in. spark were: Given a certain amount of energy to work with, the Roentgen-ray intensity, as measured by the illumination of the fluorescent screen or the action on the photographic plate, goes up rapidly with the voltage. This is obvious from the well known fact that Roentgen-ray intensity, measured as above, increases with the first power of the milliamperage and with the square of the voltage, while the energy delivered to the tube is proportional to the product of the first power of the current and the voltage. This, then, was an argument in favor of high voltage. On the other hand, contrast, in both radiography and fluoroscopy, decreases with increasing voltage. This is an argument against the use of too high voltage. The voltage corresponding to a 5-in. spark between points appeared to be a good compromise.

The authors have adopted the following general method of using the outfit.

After starting the engine, the resistance (b) is all cut out. This causes the engine to idle at its lowest speed.

For radiographic work, the resistance of (b) is raised until the line voltage indicated by (c) is about 160. The filament current is then adjusted once for all* by means of the control (D) until, upon closing the X-ray switch, the milliamperemeter registers 10. As the X-ray switch is closed the line voltage is seen to drop. The resistance of (b) should be changed until the line voltage, with the 10 ma. load, is 122. The line voltage is now observed when the load is taken off, and is in future work brought to this point before closing the Roentgen-ray switch. The important point is that the voltmeter reading when the 10 milliampere load is on shall always be 122. If this condition is fulfilled, all radiographic work will be done with a tube voltage corresponding to a 5-in. spark between points.

For fluoroscopic work, it is not necessary to touch the filament current control. This should be left just as it was for radiographic work. After closing the Roentgen-ray switch, the rheostat (b) is so adjusted that the tube carries 5 milliamperes. The tube voltage will then be the same as it is with the 10-ma. setting for radiographic work.

ENGINEERING DATA

(1) Electrical Efficiency

Wattmeter measurements taken at various points in the circuit showed that, with the radiographic load of 10 ma. at 57,500 volts (effective), the alternating-current generator was delivering 820 watts, and that this energy was consumed in various parts of the outfit as follows:

	Watts
Main line loss	10
Booster loss	12
Filament-current control loss	14
Filament-current transformer loss	5
Energy consumed in filament	43
Energy delivered to Roentgen-ray transformer	694
Total	778

* It should subsequently need to be changed only when tubes are changed.

The difference of 5 per cent between this total and the 820 watts measured directly at the brushes of the generator is doubtless to be explained in part by experimental error and in part by distortion of wave-form.

From the above, it is seen that 85 per cent (694 watts) of the energy from the generator is delivered to the Roentgen-ray transformer.

The energy in the high-tension discharge passing through the tube was not measured directly. (If time had permitted, it would have been determined by thermal measurements of the heat generated in the target.) It should be approximately equal to 575 watts (the product of tube current and voltage, or 0.010 by 57,500). *According to this, the Roentgen-ray tube gets, in the form of high-tension discharge, 83 per cent of the energy delivered to the Roentgen-ray transformer and 70 per cent of the total energy delivered by the alternating-current generator.*

(2) Gasolene Economy

This was determined for various Roentgen-ray loads. In the following table, the first column gives the number of the experiment, the second the load, the third the engine speed in revolutions per minute, the fourth the dynamo voltage, and the last the economy expressed in hours of operation per gallon of gasolene consumed.

Expt. No.	Roentgen-ray Load	R.p.m.	Dynamo Voltage	Hours per Gallon
1	0	900	90	$5\frac{1}{2}$
2	0	1440	160	4
3	Radiographic	1382	122	$3\frac{1}{2}$
4	Fluoroscopic	1320	114	$3\frac{3}{4}$

In Experiment 1, the engine was idling at its lowest speed and the Roentgen-ray switch was open. In Experiment 2, the engine speed was that required for radiographic work, but the Roentgen-ray switch was open. In Experiment 3, the radiographic load is on for 15 seconds and then off for the remaining 45 seconds of each minute. (This particular schedule was chosen as representing the severest radiographic service which was likely to be required of the outfit.) The fourth experiment was with a fluoroscopic load kept on continuously.

(3) Weights

The weight in pounds of the different parts of the outfit is given in the following table:

Engine and generator, with wooden base	377 lbs.
Tube-box, and shutter	110 lbs.
Table	164 lbs.
Transformer and instrument box with contents	244 lbs.
Total	895 lbs.

ADVANTAGES OF THE OUTFIT

The advantages of the complete outfit, as described above, may be summarized as follows:

(1) Simplicity of apparatus.

(2) High efficiency with consequent light weight and portability.

(3) No moving parts other than the gasolene-electric set.

(4) Control of line voltage, making it possible to duplicate electrical conditions and X-ray results very accurately.

(5) The tube has been designed to carry all of the energy that the generator can deliver. For this reason no harm can be done to the tube by raising the filament current too high. Under such conditions the milliamperage will go up, but the voltage will decrease so that the energy delivered to the tube will not go up appreciably.

(6) The gasolene-electric set can be placed at any desired distance from the high tension part of the outfit, so as to avoid noise in the operating room.

(7) No storage battery to get out of order.

(8) Engine can be made to idle at very low speed, conducive to long life. This advantage comes from the use of the voltage governor instead of a speed governor.

(9) An accidental short circuit of the generator does no harm; it simply lowers the line voltage to such an extent that the field excitation goes down, the ignition fails, and the engine stops.

IMPROVEMENTS WHICH COULD BE MADE BY SPECIAL DESIGN

The outfit described was developed primarily for army use, and the exigency of the case made it necessary, in so far as possible, to make use of parts which were already in production and hence readily available. It could be further simplified and improved by special design.

The greatest improvement would come from a reduction in the "inverse" voltage. By proper electrical design of the dynamo and the high-voltage transformer, this "inverse" voltage could readily be reduced to a point where it would be but slightly in excess of the "useful" voltage.

This would make it practicable and easy to work with a high-tension system grounded on one side. The cathode of the tube would then be connected to the lead covering of the tube box, and through this and the supporting mechanisms to the grounded metal frame of the table. There would then be only one high-tension terminal to the transformer and only one high-tension wire going to the tube (to the anode). The grounding of the cathode end of the tube would make it possible to dispense with the relatively bulky filament-current transformer insulated for high potential and to replace it with a very small ordinary low-voltage transformer. It would also, for the following reasons, increase the allowable tube travel: first, the grounded end of the tube could safely be moved to the extreme end of the table; and, second, owing to the reduction in inverse voltage, the length of tube and tube-box could be materially reduced.

The set described is intended to be used as a unit; but it would be a simple matter to so modify it that it could be operated from existing electric circuits without running the gasolene-electric set. The wiring diagram (Fig. 6) shows the simplicity of such a system. Where different line voltages are to be encountered, the Roentgen-ray and filament-current transformers would have special primary windings with several taps, or with several sections which could be connected in series or in multiple. Another method of accomplishing the same result would consist in using an auto-transformer provided with suitable taps to take in current of any commercial voltage and deliver it at the 122 volts given by the Delco-light set. There is already sufficient iron in the transformers to take care of a wide range of frequencies. For operation from direct-current mains, a rotary converter would be needed. When operating from existing electric mains, with either alternating or direct current, the booster would not be needed.

In closing the authors wish to express their thanks to the many different manufacturers who loaned the apparatus used in the investigation of the different systems referred to in this article.

Methods for More Efficiently Utilizing Our Fuel Resources

PART IX. HYDRO-ELECTRIC ENERGY AS A CONSERVER OF OIL*

By H. F. JACKSON

PRESIDENT PACIFIC COAST SECTION, NATIONAL ELECTRIC LIGHT ASSOCIATION

and

F. EMERSON HOAR

GAS AND ELECTRICAL ENGINEER, CALIFORNIA RAILROAD COMMISSION

The Petroleum Committee of the California State Council of Defense has given careful consideration to two special reports, by the above authors, treating of the possibilities of further conservation of California petroleum by more extensive and efficient utilization of hydro-electric energy. The following article, which is an abstract of the reports, views the present oil shortage in a practical manner, and concludes that the earliest possible relief would result from a greater use of the hydro-electric power that can be made available by the interconnection of the more important transmission systems.—EDITOR.

Owing to the limited extent of the coal deposits in California, Oregon, Washington, Nevada, and Arizona, these states are large users of California petroleum as fuel for industrial purposes. However, the conservation of this fuel by the substitution of water-power has been practised in California and the other Pacific coast states, as will be apparent from the fact that the hydro-electric development in California has increased 800 per cent in the last fifteen years. It is interesting to note that during the same period, the production of petroleum has increased less than 700 per cent.

The total installed capacity of existing hydro-electric plants in California, Washington, Oregon, Nevada, and Arizona is about 1,288,600 horse power, of which 731,000 horse power or 56.8 per cent is in California. The combined output of these hydro-electric plants, if reproduced by steam power, would require the annual consumption of not less than 19,000,000 barrels of fuel oil.

Water-power Resources of the Pacific States

The minimum potential water-power resources of California, according to estimates,† is 3,424,000 horse power; and the minimum combined resources of the five states mentioned is reported to be 12,619,000 horse power, or 45 per cent of the water power resources of the entire country. Of these potential resources, approximately one-third can be developed as required at an average investment cost which will permit of successful and profitable operation under present conditions of the western power market.

Information on this subject, segregated by states, is given in Table I.

The vast water-power resources of California, and those other states which are now

TABLE 1

WATER-POWER RESOURCES AND HYDRO-ELECTRIC DEVELOPMENT IN THE PACIFIC COAST STATES IN HORSE POWER

	California	Oregon	Washington	Nevada	Arizona	Totals
Minimum potential water power resources	3,424,000	3,148,000	4,928,000	172,000	893,000	12,619,000
Estimated practical developments under present conditions....	1,100,000	950.000	1,200,000	20,000	280,000	3,550,000
Installed capacity of hydro-electric plants:						
1902............	91,656	31,089	24,089	2 296	320	149,450
1907............	216,150	138,779	67,714	6,812	934	430,389
1912............	440,243	168,807	279,760	12,709	9,346	910,865
1917 (estimated)...	731,000	176,800	333,600	13,500	33,700	1,288,600

* From the *Journal of Electricity*, October 1, 1917, p. 299.

† Made by the U. S. Geological Survey in 1908, revised by the Commissioner of Corporations in 1912 and by the Secretary of Agriculture in Senate Document No. 316, Sixty-fourth Congress, first session.

consuming California petroleum, are of particular interest at this time because of the present critical situation affecting the supply of liquid fuels. The only relief, however, which may be anticipated from these resources during the war will come from a more complete and efficient utilization of existing hydro-electric capacity.

Interconnection of Power Systems

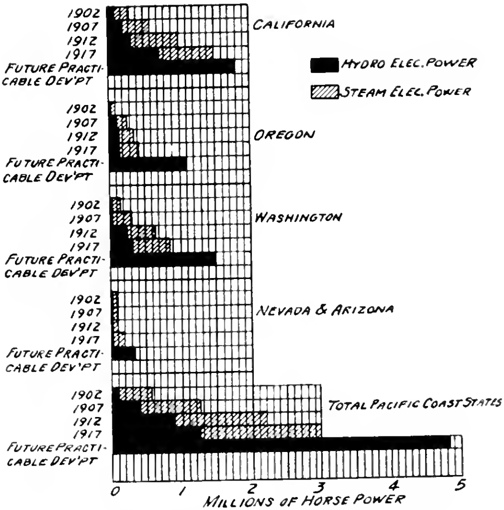
At the present time over 21,500 horse power of developed hydro-electric plants in California are not available for use in the industrial centers of the state, because of inadequate line capacities and lack of proper interconnections between the systems of the larger producing companies. The annual output capacity of this excess power is equivalent to about 668,500 barrels of fuel oil. In addition to the unavailable actual excess capacity in hydro-electric plants of the individual companies operating in California, the failure to take advantage of the diversity between the system peak loads of these various companies and the inability at the present time to fully utilize the stream flow at the separate plants, because of the lack of interconnections between the individual transmission systems, represent a waste of electric energy which is equivalent to not less than 1,100,000 barrels of fuel oil annually. Adequate and proper interconnections between the larger independent transmission systems would remedy this situation.

Existing Steam Plants

The present installed capacity of public utility and industrial steam-power plants in the five Pacific coast states mentioned is shown by Table II to be about 1,729,600 horse power, of which total approximately 804,900 horse power is installed in California.

The present fuel oil consumption of these steam-power plants is at the rate of about 9,770,000 barrels per year, of which amount some 3,950,000 barrels are consumed in California outside of the oil fields.

Railroads at the present time consume approximately 33,996,000 barrels of California fuel oil per annum, of which amount about 24,790,000 barrels are consumed by railroads in California and other Pacific coast states.



Hydro-electric and Steam Power Development and Water-power Resources, Pacific Coast States

Internal Combustion Engines

In addition to the steam plants consuming California fuel oil, stationary internal combustion engine plants are relatively large users of gasolene and distillates. The capacity of the engines installed in manufacturing establishments in the five Pacific coast states is at the present time approximately 17,980 horse power. These installations have decreased continuously during the last ten years as shown by Table III.

TABLE II

PUBLIC UTILITY AND INDUSTRIAL STEAM PLANT INSTALLATIONS IN THE PACIFIC COAST STATES IN HORSE POWER

	California	Oregon	Washington	Nevada	Arizona	Totals
1902	220,937	59,404	140,110	1,156	16,498	438,105
1907	397,986	114,132	263,016	3,392	34,973	813,499
1912	664,987	196,112	393,276	8,808	56,787	1,319,970
1917 (estimated)	804,900	267,800	522,000	22,400	112,500	1,729,600

Railway Electrification

While the greatest individual saving in fuel oil would be attained through the electrification of the mountain divisions of steam railroads in California over the Siskiyou, Sierra Nevada, and Tehachapi grades, this is a matter for the future rather than one which can be counted upon to relieve the present day shortage. Such a comprehensive plan for the substitution of hydro-electric energy for fuel oil could not be carried out immediately; and the benefits resulting from such a change would, if immediate steps were taken to begin construction, not be realized for two and a half to three years. The saving in fuel oil by the electrification of the mountain divisions of the principal railroads would be from 3,200,000 to 3,800,000 barrels per year. The expense involved in making the change would be from $17,500,000 to $20,000,000.

Conservation of Oil

The substitution of electric power for that produced by internal combustion engines accessible to existing electric distribution lines in California would, in all probability, effect an annual saving of about 550,000 barrels of gasolene and engine distillate. In order to accomplish this result fully, however, it would be necessary to develop considerable additional power, which presumably will not be practicable during the war because of the impossibility of obtaining immediate delivery of equipment and of the time required to develop hydro-electric resources.

Viewing the matter from a practical standpoint, the only relief which can be anticipated from a greater use of hydro-electric energy will result from the interconnection of the more important electric transmission systems, thus making usable a larger proportion of the available developed water power. This additional energy, if utilized for power purposes by the present public-utility and industrial users of fuel oil, would permit the almost immediate conservation of approximately 1,500,000 barrels of fuel oil per year.

TABLE III

PUBLIC UTILITY AND INDUSTRIAL GAS AND OIL ENGINE INSTALLATIONS IN THE PACIFIC COAST STATES IN HORSE POWER

	California	Oregon	Washington	Nevada	Arizona	Totals
1902	10,111	475	1,218	262	2,120	14,186
1907	27,788	667	1,776	965	1,833	33,039
1912	13,832	906	1,764	1,266	1,115	18,883
1917 (estimated)	13,000	1,000	1,750	1,440	780	17,980

PART X. OUR FUTURE PETROLEUM INDUSTRY*

By W. A. Williams

Assistant General Manager, Empire Gas and Fuel Company

In this article the author discusses the sources of our future supply of gasolene and states that a very important source of future supply is in the tremendous latent reserves of petroleum in oil shales. In limited areas, it is estimated that there is available more than *fifteen* times the past and future production of petroleum; but the cost of production will prevent the use of oil shales until the price of petroleum products increases owing to the law of supply and demand.—Editor.

Since the discovery of oil by Colonel Drake, in 1859, we have produced to January 1, 1917, 3,944,000,000 barrels of oil and we are today producing at the rate of 300,000,000 barrels of oil per year, or approximately two-thirds of the entire world's production of crude petroleum. Will we be able to increase this production to meet increased future demands for petroleum products, and if so, how? Will we be able to maintain our present rate of production for any considerable period? Will domestic production, supplemented by foreign production, meet future demands? What other supplies are available to supplement our present sources of petroleum products?

Our Petroleum Resources and Production

Probably the most reliable estimate of our future petroleum resources was made by the United States Geological Survey in February, 1916. The estimate of our future supplies of

* From the *Doherty News*, September, 1917, p. 9.

petroleum, from both the known and the prospective fields, was approximately 7,000,-000,000 barrels, which at the present rate of production would be sufficient to last a little less than twenty-five years.

Table I is a résumé of the Survey's estimate, showing the past production, the estimated future production, and the estimated percentage of exhaustion of the different fields.

Since this estimate was prepared, drilling has been extremely active in all fields, 25,000 wells being completed in 1916 as against 15,000 in 1915; also, during this period the application of geology to oil finding has become general. Prior to 1915 very few companies employed trained geologists, while today most of the large companies and a majority of the independent producers are following the advice of the geologists in the search for new fields and production. Still the new production developed during the past year was little more than sufficient to offset the normal decline of production of the older fields. On the whole the Geological Survey estimate appears to be liberal, especially so in the states of Montana, Wyoming, California and Oklahoma.

Unqualified the above statement would reflect upon the stability of the oil industry; but when carefully analyzed in the light of the laws of supply and demand it cannot but impress one with the soundness of this industry. The production of all our petroleum within the next twenty-five years would be an absolute physical impossibility. From year to year it becomes increasingly more difficult to find new fields; oil reserves must be maintained, and the physical laws of drainage must run their course. We will probably be producing oil and opening new fields a hundred years from now. In the meantime, the demand for petroleum products is increasing by leaps and bounds, due to the increased use of the automobile and to our general industrial growth, while our crude oil production has remained approximately stationary.

TABLE I

Field	Production, Including 1916 (Millions of Barrels)	Petroleum Remaining in Fields (Millions of Barrels)	Estimated Percentage of Exhaustion of Total Oil Content
Appalachian	1173	458	72
Lima-Indiana	446	23	95
Illinois	268	233	54
Mid-Continent	736	1755	29
North Texas	54	474	9
Northwest Louisiana	69	113	38
Gulf Coast	253	1484	15
Colorado	12	5	70
Wyoming and Montana	24	528	4
California	922	2278	29
	3944	7337	35

More Efficient Methods for Production and Utilization

Many of the leading authorities believe that we have about reached the crest of our crude oil production in this country, and that the inevitable decline must set in within the near future. The effect of this decline will be offset temporarily, at least, by more efficient methods of production and more efficient utilization of our available supplies. The present methods of mining oils are wasteful and leave more than 50 per cent as unrecoverable oil in the ground, half of which, authorities state, can be considered as possibly recoverable oil.

We efficiently utilize less than 40 per cent of our present production. The remaining 60 per cent is being sold, in most cases, at less than cost in order to market accumulated distillates, for which the demand is limited, necessitating their sale in unnatural competition, such as with coal for fuel purposes. Our future supplies of coal at the present rate of production have been estimated to be adequate for some 3000 years, whereas our oil supplies have been estimated to be adequate for less than one-hundredth of this time. Our first problem will be to convert into more valuable and necessary products that portion of our petroleum which is not being efficiently utilized. This may be accomplished by the development of successful "cracking" processes which will convert the heavier distillates into much needed motor fuels.

Refiners throughout the entire country have been concentrating their attention for the last year and a half on the development of such processes, with a result that there are a large number of patented "cracking" and conversion processes on the market today, only one of which (the Burton process) is in general commercial use.

The Rittman process, which must still be considered as undeveloped, promises important results within the next year, as it has certain latent advantages over the Burton process, due to flexibility of temperature and pressure control.

The "cracking" processes developed to date can be divided into two classes. One, the two-phase system, in which "cracking" takes place in the presence of both liquid and vapor, as in the Burton process, and in which the pressure and temperature are interdependent, high temperature being accompanied by correspondingly high pressure; and second, the one-phase system, in which "cracking" takes place in the presence of vapor only, as in the Rittman process, the temperature and pressure being independent, high temperatures favorable in "cracking" being attainable without the correspondingly high pressures. The commercial advantage of the one-phase system over the two-phase system is that kerosene can be "cracked" in the one-phase system without the excessive pressure which makes its use in the Burton process prohibitive. Furthermore, temperature control, independent of pressure, is an important advantage in the manufacture of many possibly valuable by-products. With the large amount of attention that is being directed on "cracking" today, it will not be long before we are efficiently utilizing the larger portion of our production.

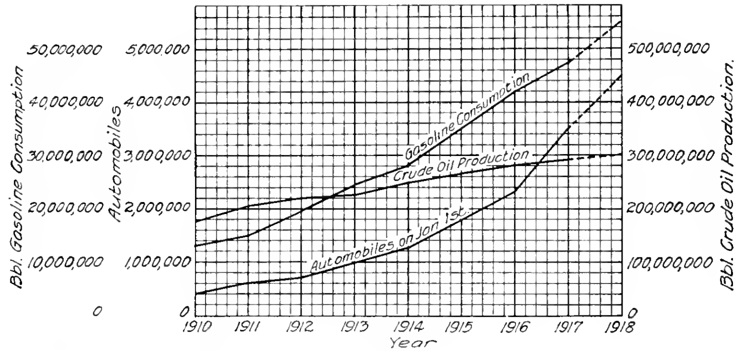


Fig. 1. Curves showing Crude Oil Production, Number of Automobiles, and Gasolene Consumption

Sources of Petroleum in Latin America

Our most available sources of production from foreign countries would be Central and South America, and especially Mexico. The general opinion of those best informed is that while there are certain favorable surface indications in Central America, there is little likelihood of the production of these countries becoming an important factor in the production of petroleum. South America, especially Colombia and Venezuela, are decidedly promising, but it is doubtful if South America as a whole will ever become an important factor in the world's production of petroleum.

Mexico, on the other hand, is the most promising and dependable of all foreign countries. The information available to date as to Mexico is altogether too limited for one to even hazard a guess. *Most of the past production of Mexico has come from two wells,* notwithstanding the fact that more than 700 wells have been drilled to date. Considering future possibilities, one is likely not to give sufficient consideration to this fact. Mexico undoubtedly contains a large future supply of petroleum, the natural market for which is the United States. We are even now importing more than 75 per cent of this production. Relief from this source, while material, will not probably be sufficient to maintain our increased requirements for any considerable period of time.

Collecting Distillates from Coal and Wood

Germany today is supplying her army and aeroplane motor fuel requirements largely from coal. We could do a lot if we more efficiently utilized our coals. By doing this, and by scrubbing our artificial gas, and collecting such distillates as can be utilized for motor fuels, it would be possible to add considerably to our motor fuel requirements, at the same time improving the coal for fuel purposes.

Some progress is being made in the distillation of alcohol from wood, which might supplement the use of petroleum, as motor fuel for some purposes, but it is doubtful if it ever would be produced in sufficient quantities to justify its universal use in automobiles, unless some modification of the engine would readily permit switching from one fuel to the other.

The curves of Fig. 1 show the rate of increase in the consumption of motor fuels, the increased number of automobiles in service January 1st of each year, and the crude oil production of this country to date.

Our Oil-shale Resources

Our most important source of future supply is in the tremendous latent reserves of petroleum in oil-shales. The United States Geological Survey and Bureau of Mines have investigated limited areas of these shales in Colorado and Utah; and from an area of some 3000 square miles, which they estimate is underlaid by more than 50 feet of workable shale beds of more than three feet in thickness, the average yield determined by test was over twenty gallons per ton. It is estimated that this area alone contains in excess of 150,000,000,000 barrels of oil, or more than fifteen times the past and estimated future production of petroleum.

When it is considered that future investigations will undoubtedly reveal other important oil-shale deposits throughout the country, these figures cannot but help to lend stability to the oil industry; and if our demands for motor fuels continue to increase at the present rate, it will only be a comparatively short time—five to ten years—before we will have to depend on oil shales, as well as foreign oil to supplement our domestic supply.

The important question is asked, how is the production of petroleum from shales going to affect the production from present sources of supply? The present source is, or will shortly be, inadequate to meet our future requirements, and we must rely upon other supplies. The cost of mining, transporting, and retorting shales makes the working of these deposits prohibitive today. Petroleum must increase in value before shales can be economically worked, and considering the ever increasing demands for petroleum products it must necessarily increase in value.

PART XI. FUTURE SOURCES OF OIL AND GASOLENE*

By Milton A. Allen

In the preceding article it was stated that the amount of petroleum which has been mined in the United States and that which has been rendered unavailable by inefficient mining methods totals one-third of the initial supply. Petroleum, therefore, is a very limited natural resource. In the future we shall have to obtain the greater portion of our oils and gasolene by the distillation of cannel-coal, lignite, oil-shale, and natural bitumen. This article reviews the products which may be obtained from these substances.—Editor.

A shortage of gasolene has been threatened recently and it has been announced that, if the consumption was not reduced voluntarily during the War, legislative regulation would be necessary.

Prior to the War the United States produced 65 per cent of the world's petroleum. Since then the supplies of Russia, Rumania, and Austria have been cut off, thereby placing the burden of production upon the United States. Besides this there is the ever-increasing domestic demand.

In 1914 the marketed production of American petroleum was 250 million barrels and this increased to 281 million barrels in 1915. Our estimated resources are 5,500 million barrels, or 20 years' supply at the present rate of consumption. The future source of gasolene to supply the increasing consumption and to take the place of our depleting resources is a serious problem. Most of the crude petroleum yields only a small proportion of gasolene and burning naphtha or oils that lend themselves readily to being manufactured into gasolene by cracking. The Mexican, Californian, Texan, and some mid-Continental oils are of this class. Gasolene must therefore be supplied by the high-grade paraffin-base oils. The best of these yields only 15 to 25 per cent of refined gasolene and naphtha.

The Appalachian and parts of the mid-Continental fields yield the bulk of these paraffin oils, but this represents less than 40 per cent of the total crude petroleum output in the United States. From this it is seen that our gasolene supply is limited and restricted. During the year ended June 1915, the United States exported 244 million gal-

* From *Western Engineering*, November, 1917, p. 436.

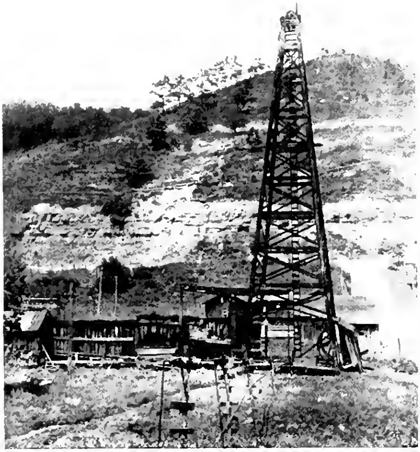


Fig. 1. Well No. 1, Henry Talkinton Lease, Fulsom, W. Va. One of the first electrically operated oil wells in America

Fig. 2. One of the Heaviest Derricks in the World, in the Coalinga Field, California. Height 106 ft. Depth of well 4200 ft.

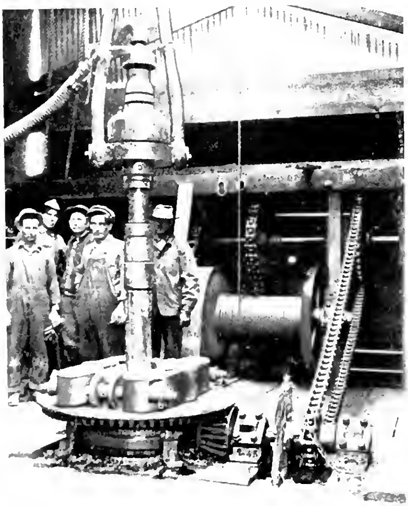


Fig. 3. Rotary Drilling Rig and Crew in the Midway Oil Field, California

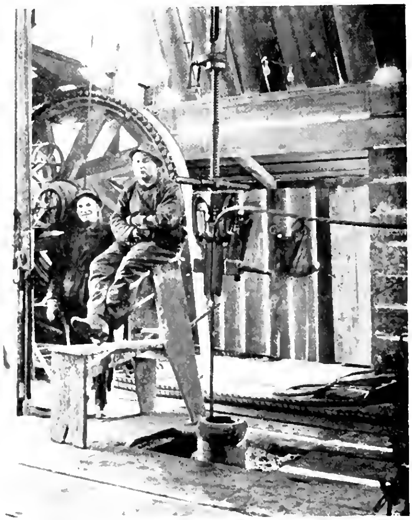


Fig. 4. Cable Tool Drilling with Motor in the McKittrick Oil Field, California

Fig. 5. Oil Wells near Taft in the Midway Oil Field, California

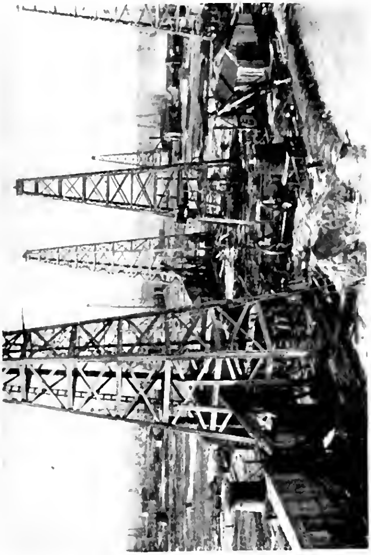


Fig. 6. View in the Spindletop Oil Field, Beaumont, Tex.

Fig. 7. Pumping Oil Wells in the Bed of the Arkansas River, Oklahoma

Fig. 8. Typical Jack Well in the Illinois Oil Field

lons of gasolene and naphtha that could have been diverted to home consumption. It will be interesting to consider the possible sources of gasolene other than crude petroleum, casing-head gasolene, and cracked gasolene.

Natural Bitumen, Coal, and Shale

The sources from which oil can be obtained in quantity for making motor-spirit are natural bitumen, highly volatile coal (lignite and cannel), and shale.

Prior to the discovery of oil in this country in the 'fifties, the cannel-coal deposits of Kentucky were mined and the coal distilled as it is in Scotland today. The oil yielded excellent lighting-oil or kerosene, lubricating oil, and tar. Similarly the albertite deposits of Canada were worked and distilled. Both these industries were forced out of the market when natural petroleum was produced in quantity.

For many years the Scottish oil-shales have been distilled at low temperatures (1000° F.). The richer shales, from which as much as 40 gallons per ton was obtained, are now exhausted; the average yield is now between 20 and 25 gallons only. In the process of distillation used, a large yield (45 lb.) of ammonium sulphate is obtained. The small yield of gas is scrubbed and used in the distillation process and for power. The crude oil is refined, yielding naphthas, burning-oils, gas-oils, lubricating-oils, and paraffin-wax. In spite of the increased price of chemicals, the improvements in retorts and in recovery together with the installation of electric power have enabled the industry to operate at a profit. It is a fact, however, that at greater depths the Scottish shale yields less oil.

Large quantities of natural bitumen, similar to albertite, are found in Utah, Oklahoma, and Colorado. It is estimated that there are 32 million tons of uintaite in the known veins in Utah alone. Analyses of albertite and uintaite follow:

	Albertite Per Cent	Uintaite Per Cent
Volatile	60.0	56.5
Fixed carbon and ash	39.5	43.0
Sulphur	0.5	1.5

Experiments made in Scotland under working conditions showed a yield of 134 gallons of oil per ton of albertite. The yield of uintaite should approach that of albertite.

Cannel-coal

The market demands for cannel-coal are limited, hence the present output is small; it is used to enrich gas in gas-works and as a grate coal in some localities. For this reason large areas of cannel-coal in Ohio, Kentucky, West Virginia, Indiana, and Tennessee have not been developed. These coals vary in volatile content from 35 to 54 per cent, and in many instances they approach 60 per cent. It is estimated that there are millions of tons of workable cannel-coal in Kentucky alone.

An analysis of a typical Kentucky cannel-coal shows the following content:

	Per Cent
Moisture	2.4
Volatile	50.3
Fixed carbon	43.3
Ash	3.4
Sulphur	0.6

This coal holds considerably less ash than the European cannels, hence the greater possibilities of disposing of the coke by-product if the coal is distilled like the Scotch shale. The coal residue could also be burned in producers and electric power generated as a by-product.

Experiments in distillation at low temperature of high volatile cannel-coal show that it yields from 35 to 60 gallons of dry tar-oil, the amount depending on the percentage of volatile matter in the coal and the temperature at which the destructive distillation is conducted. These cannel-coal tar-oils are high in paraffin, and the heavier fraction could readily be cracked to yield a high percentage of motor-spirit.

For many years in England cannel-coal was used in gas-works as an enricher; but if large quantities were employed the tar by-product was difficult to sell to the tar-distillers because of its high percentage of paraffin. This bears out recent experiments, except that the percentage of paraffin hydro-carbons is considerably increased when the coal is treated at a low temperature as in the Scotch shale distillation. The advantages of cannel-coal distillation for tar-oils over the Scotch shale would be that the residue or coke could be used for power purposes on a large scale, be sold directly, or be ground and made into briquettes. Ammonium sulphate would be a by-product as in the Scotch shale industry and the yield would probably be large. Experiments on albertite yielded 65 lb. ammonium sulphate per ton.

Apart from the tar-oils the gas when scrubbed yields benzene and toluene and some light oils. The benzene and toluene could be mixed with some of the light oils and used for purposes similar to those to which casing-head gasolene is put. Benzol has been used in France as a motor-spirit for many years.

Lignite

In many of our central, northern, and western states there are hundreds of square miles of lignite. Canadian lignite deposits, it seems, are inexhaustible. Lignite is useless there as a fuel because of its low heating value. If the lignites are subjected to low-temperature distillation they will yield from 30 to 40 gallons of dry tar-oils, depending on the volatile content of the lignite and the temperature of the destructive distillation. The residual coke can be used similarly to that from cannel-coal.

American Oil-shales

In Nova Scotia, New Brunswick, and in our western states are large areas in which oil-shale is known to exist. These shales resemble the oil-shales of Scotland. Experiments made on shales from Nova Scotia and New Brunswick yielded from 40 to 65 gallons of oil pei ton, the ammonium sulphate by-product varying from 67 to 110 pounds. The following is an analysis of these shales:

	Per Cent
Moisture	1.00
Volatile	45.32
Fixed carbon	1.29
Ash	50.69
Sulphur	1.70

In the carboniferous system of Kentucky above the cannel-coal deposits are bands of shale similar in composition: also there are separate beds of workable shale. These separate shales show the following analysis:

	Per Cent
Moisture	0.9
Volatile	43.0
Fixed carbon	13.1
Ash	42.5
Sulphur	0.5

A yield of 75 to 85 gallons of oil has been obtained from French shale deposits having the following analysis:

	Per Cent
Volatile	44.4
Fixed carbon	25.0
Ash	30.6

No sulphur exists in the oil. This resembles a high-ash cannel-coal.

From the results given, it will be seen that the shales in almost all cases give a high yield of oil. Prior to the War the oil from the Scotch shale was not cracked for motor-spirit, but there is every reason to believe that this is now being done.

Cracking of Tar-oils and Shale-oils

In crude experiments in the cracking of lignite tar-oils, after the extraction of the light naphthas, a yield of 40 per cent of motor-spirit has been obtained. It can be expected that the tar-oils of cannel-coal and the shale oils, which carry a larger percentage of paraffin oil, will yield a larger percentage of motor-fuel on cracking, and will be more amenable to such treatment. The processes now being used in the cracking of petroleum in this country are the Burton, Hall, and Rittman. The Hall process is being applied successfully in England and Russia.

The War has created a demand for benzol and toluol that did not exist before. Therefore, they were not recovered in the by-product plants. It is doubtful if these products will fall below the price of gasolene after the War because of their value as motor-spirit. Gasolene will probably not go lower.

Considering the low costs of mining and treatment of the Scotch shales by the uneconomical method practiced, it is difficult to see why the shales, natural bitumens, cannel-coals, and lignites would not yield large quantities of gasolene profitably at the present price and at the same time develop resources that are idle for want of profitable use by the adoption of a modification of the most recent continuous retorts of the type suitable for low-temperature work, together with a modern cracking plant.

Electrical Laboratory Apparatus for Educational Institutions

By J. J. Lamberty

Lighting Department, General Electric Company

For the instruction of engineering students, college laboratories should be equipped with practically all types of electrical apparatus, but the cost of separate units of each type is prohibitive for most institutions. This difficulty has been largely overcome by the apparatus described in this article, which incorporates in one design, by substitution in some cases of interchangeable rotors, a great variety of machines. For instance, the alternating-current generator may be operated as a synchronous motor, a squirrel-cage induction motor, a phase-wound induction motor, or a frequency changer by using the proper one of three rotors. Similarly the synchronous converter may be used as a direct-current generator, an alternating-current generator, a direct-current motor, a synchronous motor, or an inverted converter.—Editor.

President Wilson, in a recent letter to Secretary of the Interior Lane, emphasizes the need for engineers after the war by saying:

"There will be need for a larger number of persons expert in the various fields of applied science than ever before. Such persons will be needed both during the war and after its close."

Secretary of War Baker, in a recent address to prominent engineering educators, stated the situation clearly when he said:

"Nobody knows what the world is going to be like when the war is over. Nobody knows how long this war is going to last. But we do know that when this war is over, the rehabilitation of a stricken if not paralyzed civilization is going to be a long drawn out and uphill task, and there will be need on every hand for trained minds, for trained and schooled men. The day of the engineer will be indeed the big day. Men should then be present in very great numbers to help bring about the rehabilitation of industries, the reconstruction of an earth which has been swept by an all consuming conflagration."

Europe will have to be reconstructed after the war and such reconstruction will be largely

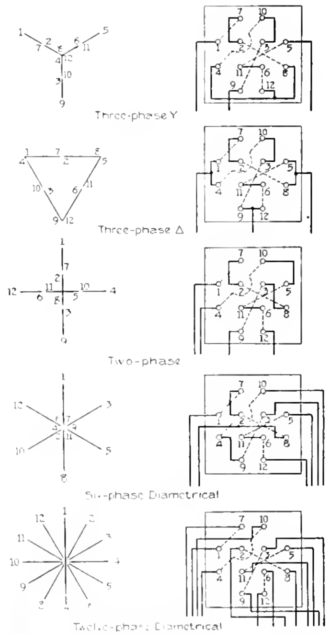


Fig. 2. Theoretical Diagrams and Terminal-board Connections for Alternating-Current Generator. Dotted Lines Represent Winding Coils

15	Kv-a., 12-phase diametrical	110 volts
15	Kv-a., 6-phase diametrical	220 volts
15	Kv-a., 3-phase "Y"	381 volts
15	Kv-a., 3-phase delta	220 volts
15	Kv-a., 2-phase	311 volts
10	Kv-a., single-phase	381 volts
7½	Kv-a., single-phase	311 volts
5	Kv-a., single-phase	220 volts

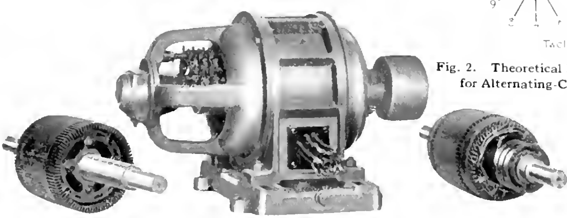


Fig. 1. 4-pole, 15-kv-a., 1800-r.p.m., 220-volt, 60-cycle Alternating-current Generator with Extra Rotors

directed by engineers. Europe herself cannot be expected to supply the demand for engineers as she will have suffered enormous losses in this field, not only through death and disability, but through the inactivity of practically all of her technical schools.

Our European allies are now reaching to America for engineers, but in America the volunteer and conscription force have materially reduced the supply of available men. Recent graduates are now in great demand by our manufacturing industries; when the war is over they will be in even greater demand. The call will be strongest for young engineers, willing to travel and eager for experience. The young electrical graduates who are familiar with the modern types of commercial apparatus will be the better fitted for the work.

Some types of modern commercial apparatus are directly available for use in a college laboratory, but electrical lighting and power machinery of today is built in sizes too large and too costly for the laboratory. Accordingly, a line of small machines has been designed that incorporate the general characteristic features of large commercial units, but of dimensions, capacities, and interchangeability of parts adapted to experimental and instruction purposes. These machines enable educational institutions to equip their electrical laboratories through a comparatively small investment of capital.

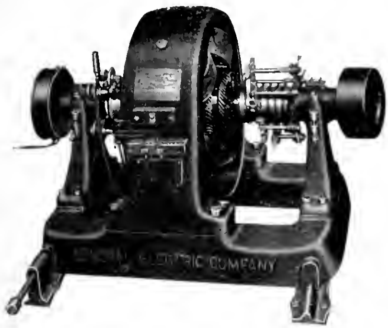
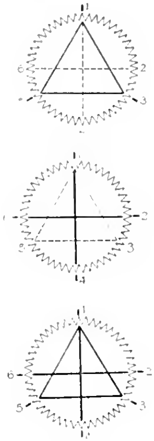


Fig. 3. 4-pole, 10-kw., 1800-r.p.m., 110-volt Shunt-wound Synchronous Converter

The alternating-current belt-driven generator shown in Fig. 1 will operate as a generator, a synchronous motor, a squirrel-cage induction motor, a phase-wound induction motor, or a frequency changer. The complete set consists of a stationary armature with a sliding base, a revolving salient-pole field, a squirrel-cage induction motor rotor, a phase-wound induction motor rotor with drum controller and resistor and other accessories.



Three-phase Voltages, 71-100, 142; Rings, 1-3-5
Corresponding d-c. Voltages, 110-160, 220

Two-phase Voltages, 82-115, 164; Rings, 1-4, 2-6
Corresponding d-c. Voltages, 110-160, 220

Single-phase Voltages, 82-115, 164; Rings, 1-4, 2-6
Corresponding d-c. Voltages, 110-160, 220
Single-phase voltages, 71-100, 142; Rings, 1-5, 3-5, 1-3
Corresponding d-c. Voltages, 110-160, 220

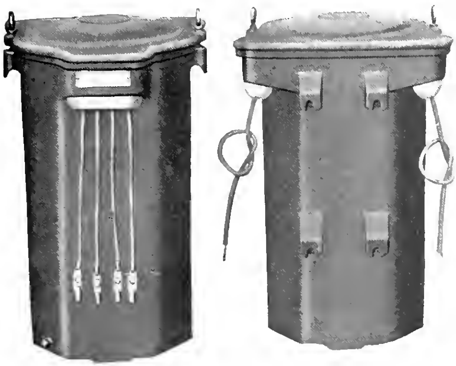
Fig. 4. Connections for Synchronous Converter

The three rotating elements of the set, namely, the salient-pole generator field, the squirrel-cage rotor, and the phase-wound rotor are interchangeable. If the squirrel-cage rotor is substituted for the revolving field, the machine will operate as a 15-h.p. constant-speed induction motor; if the phase-wound rotor is used it will operate as a 15-h.p. varying-speed induction motor.

Using the phase-wound rotor the set will also operate as a frequency changer by impressing voltage on the armature circuit and driving the rotor, the frequency and secondary collector ring voltage depending on the impressed voltage, the speed, and the direction of rotation of the driven rotor. For example, if the rotor is driven at normal 60-cycle speed in the opposite direction to which it would revolve as a motor, and if normal voltage at normal frequency is impressed on the armature, approximately 210 volts at 120 cycles is obtained.

The alternating-current generator is also built for 110 volts

The phase-displacement set comprises two of the similarly rated generators, direct connected and mounted on a common base. A spacing ring in the coupling provides for the individual operation of the machines. Each stator is provided with a shifting device so



Figs. 5 and 6. Core-type, 60-cycle, 5-kv-a., 220-volt, Primary, 82-volt (Two-phase) 71-volt (Three-phase) Secondary Transformers.

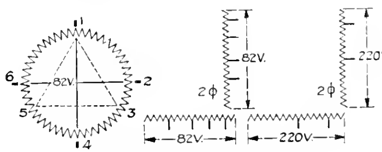
that it can be adjusted through an angle of forty-five mechanical degrees, or ninety electiical degrees.

synchronous motor, or an inverted converter. The outfit consists of a stationary salient pole field frame with a cast-iron base and rails, a revolving armature, a speed-limiting device, an endplay device, and other accessories.

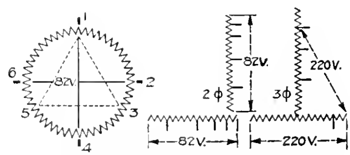
The synchronous converter is also built for 220 volts but is not designed for such a wide voltage range as the 110-volt converter. The alternating-current and the direct-current voltages for the different connections are given in Fig. 4

The regulating-pole converter is similar to the synchronous converter, except that the field is divided in two sections, namely, the main field and the regulating field. A rheostat is provided for each section of the field; one rheostat is of the ordinary type used in the shunt-field circuits of small converters, and the other of the double-dial type arranged to secure a gradual change in excitation of the regulating-field circuit from maximum *lower* to maximum *boost* without opening the circuit.

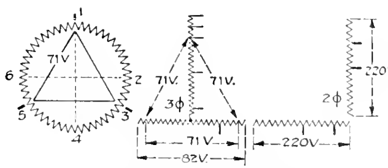
The machine will operate single-phase, two-phase, or three-phase within the voltage limits of the synchronous converter. It will also operate as a regulating-pole converter at 100 to 125 volts direct current, impressing 80 volts three-phase alternating current on rings 1, 3, and 5.



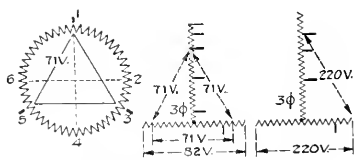
Two-phase Voltage, 82; Rings, 1-4, 2-6
Corresponding Direct-current Voltage, 110



Two-phase Voltage, 82; Rings, 1-4, 2-6
Corresponding Direct-current Voltage, 110



Three-phase voltage, 71; Rings, 1-3-5
Corresponding Direct-current Voltage, 110



Three-phase Voltage, 71; Rings, 1-3-5
Corresponding Direct-current Voltage, 110

Fig. 7. Connections of Synchronous Converter with Core-type, Two-phase, or Three-phase Transformers

The synchronous converter shown in Fig. 3 is designed to operate either as a synchronous converter, a double-current generator, a direct-current generatoı, an alternating-current generator a direct-current motor, a

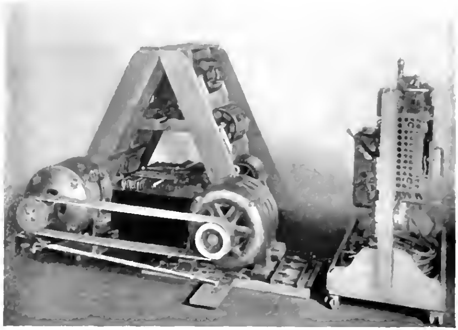
To operate as a double-current generator, an additional field rheostat with two settings is required in the regulating-pole field circuit; one setting to be used when operating as a regulating-pole conveıter, and the other when operating as a double-current generator. The equipment for this rheostat includes an interlocked concentric operating mechanism, so that both the regulating field and the main field rheostats can be adjusted by one handle.

Core-type oil-filled self-cooled transformers (Figs. 5 and 6) are designed to be used with the 110-volt converters. Two transformers with a combined output of 10 kv-a. are required. The units, with main and teaser interchangeable, have the necessary taps to operate on either a two-phase, or a three-phase 220-volt primary circuit, and in either case may be connected to deliver to the converter 82 volts (two-phase), or 71 volts (three-phase). Fig. 7 shows the various transformer and converter connections and their respective voltages.

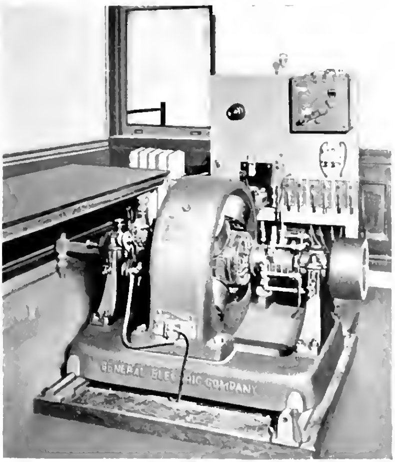
Similar transformers are built for use with the 220-volt converters.

Commercial types of switchboards are furnished to control the sets which have been described. Panels of natural black slate with dull black finished instruments are mounted on 90-inch pipe framework.

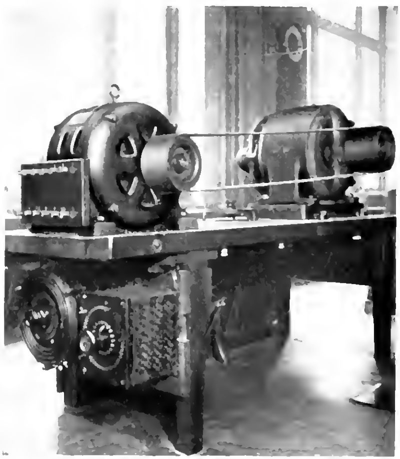
Varied arrangements are employed to take care of the different voltage and current conditions. Many of the instruments have several windings to provide for the various combinations, for instance, the wattmeter has two current coils which can be connected either in series or in parallel.



Laboratory Alternating-current Generator, University of Minnesota, Minneapolis, Minn.



Laboratory Synchronous Converter, Y. M. C. A., 23rd St., New York City



Laboratory Alternating-current Generator, Cooper Union, New York City

Life in a Large Manufacturing Plant

PART VI. APPRENTICESHIP SYSTEM

By Chas. M. Ripley

Publication Bureau, General Electric Company

The difficulty of obtaining men with the proper training for performing the exacting work demanded by many of our modern industries has led to the institution by some of the larger concerns of special training courses for boys and young men. These courses comprehend instruction ranging all the way from strictly shop training to that involving higher mathematics, physics, and applied mechanics. In most cases students are paid a nominal sum for their time, and through the existence of these apprenticeship courses many young men have been able to obtain the rudiments of a college education and acquire a trade, who otherwise could not afford to employ their time in non-remunerative work. What the General Electric Company has to offer young men through its apprenticeship courses is briefly described in this article.—Editor.

One of the problems facing most boys of 16 who are trying to choose a profession is:

1st. If I start work now I cannot get a good education.

2nd. If I get a good education I cannot start work now.

As a matter of fact, they can do *both*.

Many boys feel discouraged because they cannot go to college for four years. It is a mistake for them to think that such an education is absolutely necessary in order to get along well in the world.

Thomas A. Edison, the greatest inventor of all time, and a man whose inventions and engineering work represent nearly eight billion dollars invested capital in this country, never went to college.

Herbert Spencer, one of the greatest scientists that ever lived, and the greatest of all philosophers, was a practical mechanical engineer and inventor, but he was not a college man.

Also, the following world-famous inventors, engineers, and scientists were not college men:

Sir Henry Bessemer, inventor of Bessemer steel process.
Benjamin Franklin.
Robert Fulton, inventor of the steamboat.
Sir Hiram S. Maxim, explosives and firearms.
Hudson Maxim, explosives and firearms.
Henry L. Doherty, power plant financier and manager.
Michael Faraday, scientist and early electrical experimenter.
Alessandro Volta, scientist and early electrical experimenter.
Elihu Thomson, electrical inventor.
James Watt, steam engine inventor.
James Buchanan Eads, builder of the great bridge at St. Louis.
Isaac M. Singer, sewing machine inventor.
Elias Howe, sewing machine inventor.
William Herschel, famous scientist and astronomer.
Thomas H. Huxley, scientist.
Samuel Colt, inventor of the Colt system of firearms.
Henry Ford, intensive manufacturer.
Cyrus Hall McCormick, inventor of agricultural machinery.
Edward Weston, electrical instruments.
Alfred Bernard Nobel, inventor of dynamite.
John Tyndall, scientist.
Richard J. Gatling, inventor of the gatling gun.
John Ericsson, inventor of torpedoes, submarines and monitors.

In this chapter we will describe how boys may obtain a four-year job now, and at the end of the term, in addition to having received a good practical education, will have earned approximately $3,000. What is perhaps more important still, they will have learned three important things which are not taught in college, viz.: First, the value of a dollar; second, the independence which comes from earning one's own living; and third, the strength of character developed by working with men.

The usual college student does not receive pay while he is being educated, but the members of the General Electric apprentice courses are regularly paid while they are being educated. In these courses the young boys of America have had created for them a superb opportunity to learn to do by doing, and at the same time learn to do by being taught. It is not generally known that the General Electric Company has spent on its apprentice departments in six factories, east and west, close to $750,000 in buildings, machinery, tools, instruments, class rooms and laboratory equipment, where boys 16 years and up are initiated into the wonderful electrical manufacturing industry.

Boys should appreciate that what they learn in *practical* work they can use *right away*, and at the end of the four-year course, in addition to having earned between $2100 and $3200, they will be full-fledged journey-

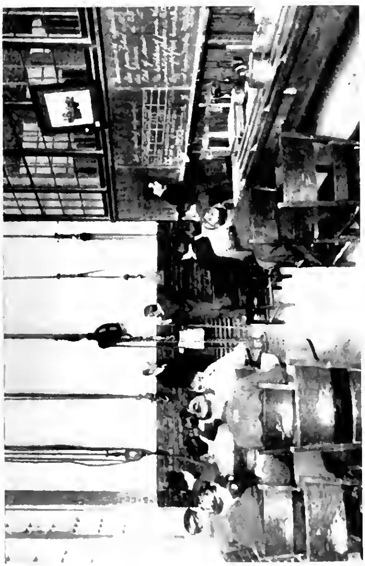


Fig. 1 Class in Mechanics, Schenectady Works

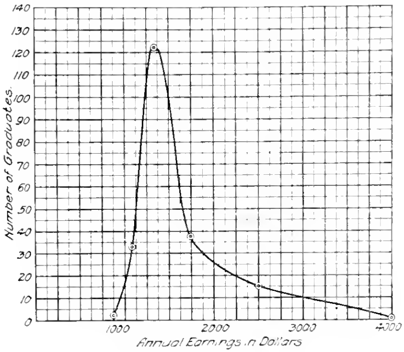
Fig. 2. Instruction in Machine Work at Lynn Works

Fig. 3. Class in Machine Design, Erie Works

Fig. 4. Class in Mechanics, Schenectady Works

men, possessed of a trade. The present graduates not only are capable of earning, but are actually employed in positions now paying not less than $0.40 an hour—a minimum of $3.20 per day.

We will describe point by point the value to a youth of establishing relations with a



Curve Showing Present Earnings of G-E Apprentice Graduates

great company, his pay and his play, the class room instructions, the homework which is expected of him, the practice afforded him by which he learns to make drawings and read blue prints, and the shop work which he does—the great variety of processes he learns to carry on, upon a great variety of machines, and with a great variety of tools.

Schenectady Works

Of the 66 boys graduated in 1916 from the apprentice course at the Schenectady Works, 8 entered the service of the U.S. Government and 50 are still working for the General Electric Company at not less than $0.40—and most of them are earning $0.50 to $0.55 per hour, and working nine hours a day. Think what it means to these boys, who in 1912 had no trade or profession and only a grammar school education, and yet who today are making $4.50 a day as established journeymen, all-around machinists, special tool makers, expert moulders, full-fledged pattern makers, and technical draftsmen! Even as important as this is, a further very significant fact is that they are in line for promotion to positions of foremen, bosses, or other executive positions.

The record of all the young men who were graduated at Schenectady shows that 65 per cent of them are now employed by the General Electric Company.

GRADUATES FROM APPRENTICE COURSES

Up to the Fall of 1917

Schenectady	980
Lynn	502
Pittsfield	80
Erie	28
Ft. Wayne	8
Total	1598

Comparison of Earnings

The following table, copied from a trade journal published just before the war, shows the average wages in cents per hour in various countries in Europe. A careful study of this will prove the phenomenal opportunity which now exists in the General Electric Company for boys of 16 years to earn $0.50 to $0.55 per hour and to become well educated technical men in a period of only four years.

AVERAGE WAGES IN CENTS PER HOUR

	Machinists
Italy	8 to 13
Switzerland	12 to 17
Germany:	
Bavaria	13 to 15
Saxony	13 to 16
Berlin	17.5 to 20
Magdeburg	14.5 to 19
Great Britain	16 to 19
Belgium	11.5 to 18

On piecework these rates may be increased 30 to 50 per cent.

What Four Years Will Do

As someone aptly remarked: "Four years is a long while for a boy to look forward to, but it is a mere trifle for a man to look back upon."

How true this is will be emphasized by considering the results of four years of combined work and instruction:

Lynn Works

Of the 502 graduates from the Lynn Works apprentice course, the majority of them are still known to their instructors, and accurate records are kept of their present earnings.

Of these graduates:

1 is earning $4,000 per year.
7 are earning between $3,000 and $4,000 per year.
15 are earning between $2,000 and $3,000 per year.
38 are earning between $1,500 and $2,000 per year.
137 are earning between $1,200 and $1,500 per year.
63 are earning between $1,000 and $1,200 per year.
2 are earning less than $1,000 per year.
239—location and salary unknown

502

Fig. 5. Class in Mechanical Engineering, Erie Works

Fig. 6. Pattern Maker Apprentices, Lynn Works

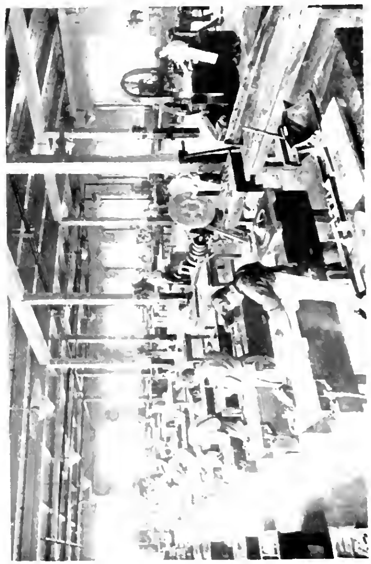


Fig. 7. Pattern Maker Apprentices, Schenectady Works

Fig. 8. Moulder Apprentices in Foundry, Schenectady Works

Pittsfield Works

An investigation of the 82 graduates from the apprentice course from that factory since 1911 discloses the fact that the earnings of 36 who are working there vary from $1150 up to $1650 per year.

Fort Wayne Works

The Fort Wayne apprentice system began in 1913, and of the first eight students who were graduated this year, one is with the United States Navy, and seven are employed as tool makers with an income of between $1300 and $1400 per year.

Erie Works

The apprentice system at the Erie Works was established and standardized about 1910, and has graduated 28 young men. Of these, seven have left, six others are employed in the U. S. Army or Navy, and 15 are with the Company earning from $4 to $6 per day.

We have considered only the wages or salaries of the graduates, but to obtain a better comprehension of the standing of these young men the positions held with the General Electric Company should be pointed out.

POSITIONS HELD BY APPRENTICE GRADUATES

4 are managers or superintendents.
35 are foremen.
18 are instructors.
15 are division leaders or assistants.
13 are tool designers.
5 are inspectors.
4 are commercial engineers
3 are assistant engineers.
2 are designing draftsmen.
2 are gang bosses.
1 is a supervisor.
1 is in charge of a section.
1 is a designing engineer.
102 are in the U. S. Government service, mostly in arsenals and navy yards, serving as skilled mechanics.

From this it might be reasonably concluded that these young men, who but a few years previous were in the grammar school, are now well established in the great electrical manufacturing business as the result of their industry and their ability to grasp the opportunity afforded them.

Statistics

Professor Robert G. Wall, in a recent address, said: "Imagine one hundred men, all twenty-five years old, and all fully equipped mentally and physically. Tell them to seek their fortunes in the world and report back to you at the age of sixty-five. In forty years' time thirty-four of these men will be dead, fifty-six will be dependent upon relatives or charitable organizations, five will still be earning their daily bread, four will be wealthy, and one will be rich. These are facts, statistics compiled by the insurance companies!"

It is quite probable that among one hundred average men, many of them never thoroughly learn any one trade; some of them probably learn a trade which will become obsolete, such as truck driving, a "trade" which is being displaced by the automobile; or the operation of steam pumps, a trade being rendered obsolete by the general use of electricity. Among other obsolescent trades are horse shoeing, the trade of the cobbler, and those connected with kerosene, gasolene, and gas lighting. It is dangerous for the future of a young man to learn a trade which will practically cease to exist during his lifetime. For instance, no one would think of learning the trade of grinding wheat by hand or setting type by hand, as automatic machines do this kind of work far cheaper and better.

If the horse, the steam engine, and the steam locomotive were to vanish from the face of the earth we could rest assured that some kind of machinery would do the work of transportation for the world—and it is not dangerous to prophesy that machinery in one form or another will not only carry on our transportation, but will become more and more used in industry, commerce, and in the home. For this reason the boy who becomes a mechanic or engineer, whether electrical or mechanical, can rest assured that that trade will not become obsolete during his life time—nor for that matter, during the life time of his great-great grandchildren.

For example, should all transportation of the future be conducted by airplane, mechanics would be needed to build air craft by the million, and probably electrical engineers would build their motors, even though the power would be supplied to them by wireless. So no matter how great the progress the world may make along these lines, a young man is making no mistake in learning the mechanical or electrical trade, both of which will be needed to turn the wheels of industry and commerce in the future.

Hence, the young man who enters the electrical profession has a better opportunity of being self-supporting at the age of sixty-

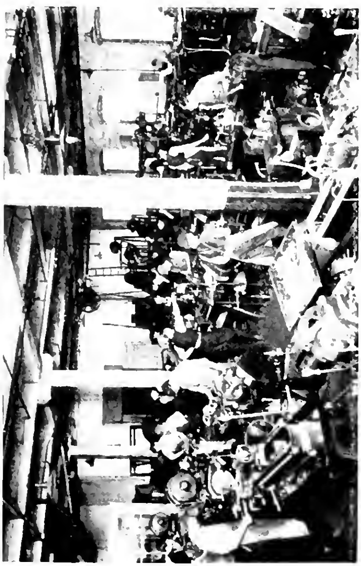


Fig. 9 Training Room for Machinist Apprentices, Fort Wayne Works

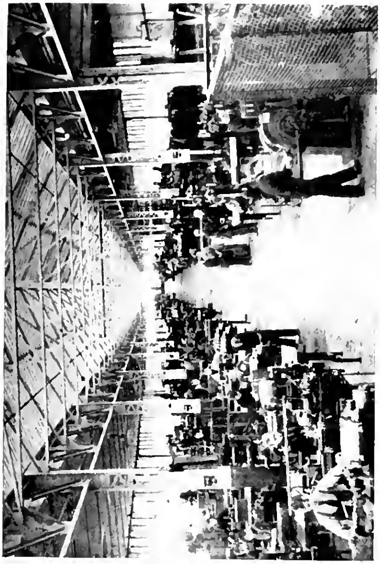


Fig. 10 Training Room for Machinist Apprentices, Lynn Works

Fig. 11 Training Room for Machinist and Tool Maker Apprentices, Erie Works

Fig. 12 Training Room for Machinist and Tool Maker Apprentices, Schenectady Works

five than in almost any other profession imaginable, because America, and, in fact, the entire world, is entering upon an electrical epoch comparable in significance with the stone age, the bronze age, the iron age, and the steam age, through which it has passed successively up to the present. Therefore, our apprentice graduates need have little fear of being classed as "dependent" if they studiously pursue the fascinating work of electrical engineering and production.

Class Room Instruction

From the illustrations it will be seen that these apprentice courses include class room instruction and practical work with intricate machine tools in modern machine shops, foundries, pattern shops, drafting rooms, etc. There is nothing more fascinating to the growing youth than to see this practical work link up with the theoretical class room instruction and vice versa. There is no joy in a student's life greater than an appreciation of the fact that what he learns in the class room—algebra, plane and solid geometry, logarithms, trigonometry, descriptive geometry, etc., is of direct assistance to him in shop practice. Here is that union between the work of the head and the work of the hand which makes for great industrial nations a place in the commerce and industry of the world, and which, moreover, has been found so necessary in carrying on the great war.

Home Work

The home work of the apprentice pattern maker and machinist consists in making 28 complete mechanical drawings, including lettering, dimensions and details; and they must solve mathematical problems in order to be able to recite in the class rooms. The draftsman apprentices have more home work than either of the two mentioned, as they are not only required to prepare the 28 drawings, but have to go into higher mathematics, which is necessary for the calculations of designing engineers.

The apprentice boys in the moulders course may be considered as the highest paid of all, because in their fourth year they receive the regular journeyman's wage, which at the present time is $0.50 per hour for an eight-hour day. There is no home work in this course, but the class room work is after working hours, which, in a measure, equalizes their advantages in the higher rate of wages.

Personal Instruction

The element of personal instruction in these apprentice courses is carefully provided for in three ways:

1. *Class Room Instruction*—The classes are kept small, generally not exceeding twenty in number, and some classes have less than twelve students. Considerable latitude is allowed in the asking of questions and the explaining of possible obscure points. In some courses the class room instruction is 10 hours in every 50 hour week.

2. *Personal Attention in Training Shops*—For all beginners in the trades—moulder, pattern maker, draftsman, and machinist—there are provided special training shops where they are given individual instruction under competent men engaged for that purpose.

3. *Personal Attention in the Shops*—As the students become more advanced they are transferred to the regular shops where their education is continued under the direction of the foreman of that department and his assistants.

Mastering the Use of Tools and Machinery

At the end of the course in the machinists trade the boy, who slightly over four years ago was in the grammar school, has become a full-fledged journeyman and is fully competent to operate the machinery found in the ordinary machine shop, such as drill presses, lathes, planers, shapers, boring machines, universal grinders, gear cutters, and threading and milling machines. In addition to these machines, the boy is able to work successfully on the bench with file, hammer, and chisel.

Equally skilled in the use of the tools of their trade are the graduates from the moulder's course, pattern maker's course, draftsman's course, and blacksmith's course. Thus men are trained to design machinery and perform the necessary calculations; others to make the patterns and the moulds in the foundry and pour in the molten metal, to machine the castings to dimensions accurate within one-thousandth of an inch; while still others are working the steam hammers for making forgings, or delicately tempering certain parts, or making tools for turning out other parts. Such is the complete scope of the training of apprentices in electrical manufacturing.

We will omit a detailed description of the practical shop work and the class room instruction, as this can be supplied to all inquirers in the form of a separate illustrated booklet exhaustively treating the different courses in detail and showing photographs

Fig. 13. Moulder Apprentices, Erie Works

Fig. 14. Machinist Apprentice Laying out Work in Shop

Fig. 15. Noon Hour, Machinist Apprentice Department

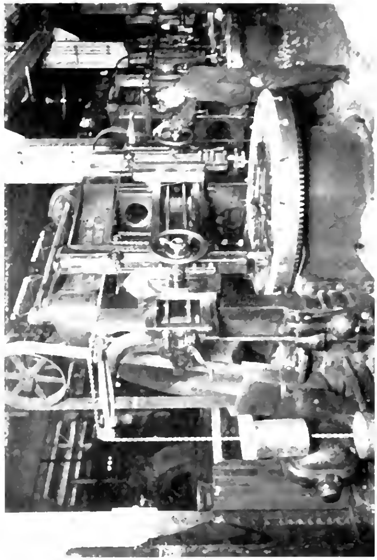


Fig. 16. Machinist Apprentices Operating Large Boring Mills, Schenectady Works

of the work which the apprentice boys turn out before their graduation.

Special Courses

In addition to the apprentice courses mentioned there are, at the Lynn Works, other training courses for electrical test men, technical clerks, cost accountants and engineering courses of a special nature. These are maintained to train young men for efficient service in the various branches of the Company's complex activities, or in power and lighting stations, transportation companies, and other industrial establishments using electrical machinery and steam apparatus.

There is also a course for those desiring to learn the business of installing and erecting electrical and steam machinery. These latter apprentice courses last but three years and a complete high school education is necessary in order to be eligible. The graduates of the electrical testing course are eligible to a special student engineering course of two years—amounting practically to a post graduate training.

A novelty in apprentice training has been introduced at Lynn, known as the co-operative course with the Massachusetts Institute of Technology, in which the students alternate three months with the "Boston Tech." and three months in the apprentice shops. This course has been arranged to cover a period of two years.

At the Erie Works, which specializes in the manufacture and design of electrical railway equipment, considerable stress is laid in the apprentice courses on railway equipment; and in the mechanical and electrical class rooms, in addition to the regular equipment, are air compressors, cylinders, safety valves, motorman's valves, air tanks, strainers, mufflers, etc., all to familiarize the apprentice with the operation and fundamental principles of electric passenger and freight locomotives and trolley cars.

At the Pittsfield Works a new course of a post graduate nature has recently been instituted in which young men graduating from the regular apprentice courses may take up advanced work and enter the transformer engineering department and the testing department. The advantage of this graduate course is that it covers a gap which formerly existed between the apprentice course and the course given the test men. With the former system it was impossible for an ambitious young man, unless a college graduate, to enter the engineering department. With the new system he is enabled, if ambitious, to reach any position in the engineering department. This work brings the student in contact with the problems associated with the transmission of power for long distances at high voltage.

PRESENT NUMBER OF APPRENTICES

December, 1917

Lynn	335
Schenectady	302
Pittsfield	113
Erie	85
Fort Wayne	82
Harrison	20
Total	937

Equipment and Facilities

There has been invested in buildings, machinery, tools and classroom equipment, over $650,000 to provide for the training of apprentices. This investment has been divided between the six different factories named in the table. The most elaborate facilities are found at the Lynn Works, where the machinists' training room alone occupies 3600 sq. ft. in one building, a space 80 ft. wide by 450 ft. long. An avenue block in New York City is only 200 ft. long, and from this fact and the view shown in Fig. 10, a conception may be gained of the importance which this work occupies in the General Electric organization. This section is filled with intricate machines of all kinds, many of them automatic, and all with individual electric motor drive. To the average citizen the operation of any one of these machines would be considerably more baffling than a Chinese puzzle, and yet the graduates master their every detail, and soon learn to turn out finished machinery with only 0.7 of 1 per cent spoilage. They learn to shape cast iron and wrought iron, steel, brass, copper, and even cotton compressed into gear blanks—all of these materials are milled, turned, cut, ground, threaded, polished, and scraped by boys in their teens.

At Fort Wayne, where the apprentice course is a comparatively new institution, there are already installed 14 lathes, 3 milling machines, 2 shapers, 2 grinders, 1 planer, 1 gear cutter, 3 bench lathes, 5 drill presses, and 1 arbor press.

At Erie the drawing class room is provided with machine parts of every description, which are cut in many different ways showing cross-sectional views, and also a complete 1-kw. gasolene generating set.

The mechanical and electrical class rooms are equipped with a machine board arranged with levers, pulleys, scales, and beams, an electrical table with switchboard on which is a lamp bank, resistance coils, voltmeters and ammeters, rheostat, and a mercury arc rectifier: and a mechanic's table with apparatus illustrating an inclined plane, a platform scale, etc. All electrical, air, water and steam apparatus is connected up, with all pipes painted standard colors.

The Schenectady Works has a slightly different scheme for handling the apprentice students, as they are more rapidly sent into the shops. All classrooms have equipment similar to that which is found in the laboratories of many technical schools. Hoists, inclined planes for demonstrating the principles of friction, weighted cords for studying the principle of the resolution of forces, sections of steam engines for studying valve systems—all these are part of the class room equipment.

Environment

There is much to be said regarding the personal life of the boys in the apprentice courses, and the character of the cities in which the factories are located.

Schenectady, a city of 97,000 population, has no "red light district." On the contrary, it has plenty of good entertainment, which is more available here than in larger cities. For instance, the American Institute of Electrical Engineers has meetings twice a month, which are addressed by prominent men such as Simon Lake the submarine inventor, Samuel Insull, Alex Dow, W. L. R. Emmett, Chas. P. Steinmetz, and other national authorities on electrical and mechanical subjects. There is a Y. M. C. A., Apprentice Alumni Association, Athletic Association, Mutual Benefit Association, a band and other musical organizations, and social opportunities exclusively for General Electric Company employees. The apprentices are eligible and welcome to most of the entertainments arranged.

Lynn, Mass., has a population of 102,000 and is a "dry" city. A rifle club, bowling club, coin and stamp club, as well as the General Electric Apprentice Fraternity, the Y. M. C. A., the Apprentice Alumni Association and band—all afford ample opportunities for social life among the young men.

Pittsfield, Mass., has a population of 38,000 and is located in the Berkshire Mountains. The climate is ideal. Various entertainments are provided by the Mutual Benefit Association, such as amateur theatricals, field days, picnics, electrical fairs, etc.

Fort Wayne, Ind., has a population of 90,000 and is approximately 100 miles from Chicago, Ill., and Detroit, Mich.

Erie, Pa., is located on Lake Erie and has a population of 75,000. Both Erie and Fort Wayne apprentices have a Club, an Alumni Association, and an annual picnic. All of the Clubs mentioned above are composed exclusively of General Electric Company men.

Thus, in these five cities, distributed along a distance of 880 miles in almost a straight line, there are opportunities for boys in the Middle West, along the Atlantic Seaboard and in New England, to work their way through these educational courses and yet not go too far from home. Lynn is practically on salt water; Pittsfield is in the Berkshire Mountains; Schenectady, amid the hills of the Mohawk Valley, lies close to the beautiful Hudson River and between the Catskill and Adirondack Mountains; while the city of Erie is situated on Lake Erie, and Fort Wayne is not far from Lake Michigan.

In all of the Works one or more complete libraries are available to the apprentices. Opportunity for baseball and boating in summer, football in the fall, skating and skiing in the winter, and track meets in the spring—all are open to all apprentices with athletic leanings.

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FEBRUARY 1918

WITH THE RENEWED AGITATION FOR THE DEVELOPMENT OF WATER POWER OUR MINDS INSTINCTIVELY TURN TO NIAGARA, THE GIANT OF AMERICAN CATARACTS

WATER POWER—OUR ELECTROCHEMICAL SALVATION

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A MONTHLY MAGAZINE FOR ENGINEERS

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VIEW OF NIAGARA FALLS FROM AIR PLANE

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GENERAL ELECTRIC REVIEW

THE NEED FOR FURTHER WATER-POWER DEVELOPMENT

Apparently it is necessary that something startling happen before we are awakened to a full realization of the conditions existing outside our individual spheres of activity. In the early days of the infantile paralysis epidemic, the potato shortage, the sugar shortage, etc., the newspaper accounts which described the conditions merely excited our superficial interest. It was not until the conditions became startlingly serious that we were aroused to an active participation in the public-spirited remedial measures.

Another such example is working itself out at the present time. For weeks past we have been informed that the distribution of coal was becoming inadequate for the demand. In the face of this shortage we went on individually using fuel unrestrictedly, feeling that somehow the situation would work out all right.

It required the unprecedented fuel-saving edict of our Fuel Administrator to make us realize that we, the consumers, are collectively joint sharers in the responsibility for the situation. It was a startling jolt; but it awakened us to the fact that we as individuals cannot day after day continue to overlook or to shirk our responsibility in matters of collective welfare.

Are we going to profit by these lessons? Are public-spirited appeals for our collective service going to claim only our reading and conversational interest until some startling fact arouses us to a conscientious realization that each and every one of us must help?

There are now claiming our attention many public matters which we are not seriously considering because they have not as yet crowded everything else from our field of vision. One of these matters is the undeveloped and underdeveloped condition of our water power. This subject is treated in this issue with specific reference to the electrochemical industry. More water power is necessary for the expansion of this industry; and the author makes an earnest plea that this development be permitted to take place at Niagara because these falls are a readily available source of cheap power and are ideally located. It is estimated that three million horse power could be developed without impairing the scenic beauty of the Falls.

* * * * * *

The products of the electrochemical industry are extremely diversified. They include aluminum, silicon, calcium carbide, cyanimid, ferro-alloys, graphite, carborundum, chlorine, etc., many of which are indispensable in the arts and in manufacture. Without aluminum the modern high-speed scout air plane would not exist; without electrochemical abrasives and ferro-alloys manufacturing processes would be lengthened many fold. Our industrial supremacy in times of peace is dependent upon these products to a very considerable extent; in the fulfillment of our stupendous war program they are vital.

One of the most important electrochemical processes is the fixation of nitrogen. and while we are not aware that any plants of this kind have so far been put into operation commercially in this country, they have been seriously contemplated, and await only a sufficient source of low-price power for realization. It is reported that Germany has obtained her entire supply of nitrates by this method during the war.

Cheap power is essential to a development of the electrochemical industry, but in order that its cheapness may not be nullified it must be available near the center of market demand for electrochemical products, and not too remote from the sources of raw material. Hence it is not surprising to find the greatest electrochemical industries in the world located at Niagara, virtually at the center of our material market.

Much thought has been given to the utilization of the great Western water powers for electrochemical purposes, but until the demand for these products in the Pacific coast states is sufficient to warrant the erection of electrochemical plants in this section, any expansion of the industry will be confined to the East. The matter of freight rates over the long haul will forever exclude competition in electrochemical products between the two sections.

The Fertilizer Industry and Its Power Requirements

By J. E. Mellett

Georgia Railway and Power Company

The author of this article is in the service of a central station company operating in a section of the country where fertilizer plants are numerous, and he has, therefore, been able to give special study to the subject of the application of electric drive to this industry. Fertilizer plants range all the way from those that merely mix the ingredients to those that manufacture and prepare all of the necessary substances, including sulphuric acid and limestone, ochre, or feldspar fillers. The power requirements of the different types of plants vary widely, depending on the size and character of the equipment. The author has specified the average requirements of the more common types of fertilizer manufacturing machinery.—Editor.

General

The manufacture of fertilizers has kept pace with other industries and has experienced a wide expansion, showing an increase of ten per cent per annum in the five years prior to the war. The importance of the industry is further indicated by the fact that in the last normal year before the war interfered, the value of materials consumed in fertilizer manufacture was over $150,000,000, the output for 1914 with its economic disturbance totaling 7,500,000 tons. In the mixed fertilizer business there are about 850 concerns operating over 1200 plants, but twelve large companies with their numerous subsidiary and affiliated concerns control more than 60 per cent of the total output, and two of them 30 per cent. Although these large companies have the advantage of superior purchasing facilities, recent statistics show that the cost of manufacturing has increased rapidly with a decline in profits.

In the face of rising costs it is imperative that the manufacturer must economize in every manner possible, and as he has no control over the price of materials that go into his product, the only relief must necessarily come through the reduction of manufacturing costs. The factories that are not using electric motors and are not familiar with the advantages to be secured from purchased service have an opportunity to reduce these costs by utilizing central station energy, which at the same time will eliminate the worries that go with the operation of a private power plant, and shift the burden and responsibility to others.

Engineers realize the advantages of electric drive and never think of recommending the old type of mechanical drive. All plants that are erected today adopt electricity as the motive power and secure service, if possible, from a central station, or if this source is not available, make arrangements for isolated generation.

In the past ten years the installation of electric motors in fertilizer plants has been on a rapidly increasing scale, involving the electrification of new plants and the changing over of mechanically driven plants, and the major portion of the power is being supplied by central stations. Nevertheless, there are a number of isolated electrically and mechanically driven plants which, if shown the way, would adopt central station service with much advantage to themselves. For the power man looking for new business and the fertilizer plant trying to generate power there should be a field for collaboration.

While only a limited number of fertilizer plants operate at capacity all the year with high load factors, the majority have fairly good load factors during the spring, fall, and winter, with light operations in the summer months; and from the central station point of view this business should prove attractive as it can be obtained at a fair rate. On the other hand, the manufacturer has no real arguments against purchased power, whether he is manufacturing his own acid and using steam for spray purposes and office heating, or whether he is buying acid. A close analysis will show that he may retain equipment for steam spray and heating, and still profit in a number of ways by buying service.

Nearly all central stations have a few isolated plants scattered over their territory that they have been trying to connect to their lines for years, and the old bug-bear of "steam required for other purposes" has killed a number of lucrative prospects in normal times. But conditions have changed in the last year, and the occasion is peculiarly fitting to begin a new drive at this time, when embargoes are the order, freight cars are being requisitioned, and fuels are away above normal.

If the central stations do not exert special effort to secure these plants now, it may prove a difficult matter to interest them when conditions again reach normal.

The plant that turned down the central station proposal a few years ago may now be awaiting a new proposition, but is too proud to bring up the subject even though it may be advantageous to do so.

Old customers should receive first consideration under the present pressure, but the fact should not be overlooked that good business can be obtained now for the future by spending a little more money than would be spent normally, in order to get such plants as have not been open to conviction in the past.

Fertilizers: Their Function and Constituents

While it is not necessary for the power engineer or salesman to know all the intricacies of fertilizer manufacture, nevertheless experience has shown that it is much easier to arouse a manufacturer's interest if the engineer indicates that he is at least familiar with the fundamental principles of the business. Therefore, it might be well to state briefly the purpose of the fertilizer industry, and to describe the product and its manufacture. The object of applying fertilizer to the soil is primarily to secure a greater yield per acre, or to maintain the present yield by adding constituents that replenish the soil with that which is taken away by crop succession. The material requirements for healthy plant life and growth may be listed under two heads; viz., organic and inorganic matters. Nitrogen, carbon, hydrogen, and oxygen are classed under the first head; phosphorous, iron, potassium, sulphur, calcium, and magnesium under the second.

Each of these elements has a definite function to fulfill in the growth of the plant, various types of plant life requiring more or less of each constituent. Nitrogen has a tendency to strengthen the growth of the fiber; phosphorous and potash, or potassium oxide, assist the fruiting; magnesium and lime act as reagents sweetening the soil; and iron assists in the leaf coloring.

The earth and the surrounding air contain all the elements which are necessary to plant life, but in order to produce intensified growth, commercial fertilizers containing potash, nitrogen, and phosphorous are generally used.

Potash (K_2O) is found in several forms, as muriate of potash and carbonate of potash. Muriate and sulphate of potash were mostly drawn from the German mines prior to the war; but they are also obtained from other sources, such as wood ashes, tobacco dust, cotton seed meal, saline deposits from the Nebraska and California brine lakes, California seaweed and kelp beds, and alunite. Several methods of securing potash are being tried out and a considerable investment has already been make in plants on the Pacific coast. The Nebraska borings show as high as 28 per cent potash, and the kelp beds of the Pacific coast bid fair to supply large quantities; but cheaper methods of extracting have yet to be found. Numerous experiments have also been made for the extraction of the small percentage of potash from feldspar and other minerals. It has been recently reported that large deposits of potash salts, averaging not less than 50 per cent, have been discovered in Abyssinia.

Of the total cost of materials in the average complete mixture, nitrogen constitutes 53 per cent, or approximately 25 per cent of the total delivered cost, and is by far the largest single element of expense in fertilizer. It is derived principally from nitrates of soda from the great beds in Peru and Chile; the fixation processes largely coming into use; coal tar and coke oven products; guano, and tankage and cotton seed. Nitrogen as embodied in commercial fertilizers is combined with other elements in the form of organic matter such as blood, tankage, cotton seed meal, and in other forms as guanos, sulphate of ammonia, nitrates of soda, nitrate of lime, calcium carbide, or cyanimide, and products from nitrogen fixation processes.

Detailed statistics of imports of nitrates from Chile to this country are lacking at present, but official publications show that we imported 13,000,000 quintals, or approximately 1,430,000 tons, in 1916, which indicates the importance of nitrates to the fertilizer and our dependence on foreign fields.

The fixation of atmospheric nitrogen, or the extraction of nitric acid from the surrounding air, has been carried on by various methods for some time, the more common being the Birkland-Eyde, cyanimide, and Badische aniline processes. It is estimated that the atmosphere surrounding the earth contains 31,000 tons of nitrogen per acre of earth's surface, or practically four-fifths of the surrounding air. Congress has appropriated large sums for the establishment of fixation plants, and no doubt the Government will soon begin to draw on Nature's storehouse through the operation of these plants.

Phosphoric acid is a combination of phosphorous and oxygen expressed as P_2O_5 and is derived chiefly from phosphatic slag,

Fig. 1. Phosphate Rock Grinding. 75-h.p., 900-r.p.m. Squirrel Cage Motor Operating 4-ton Pratt Mill and Auxiliary Equipment

animal matter, and phosphate rock which contains a high percentage of tricalcium phosphate and is secured from the larger deposits found in Tennessee, Florida, South Carolina, and a few of the Western States. The rock is received at the fertilizer plants in the form of pebbles and small rocks varying in size from 2½ to 6 inches in diameter.

Phosphatic slag is produced in the manufacture of steel by the basic Bessemer and basic open-hearth processes. The phosphorous, in the form of tetra-calcium phosphate, is separated from the iron by the addition of lime or limestone, which forms phosphoric compounds. These processes produce from 10 to 25 per cent phosphoric acid. Several methods are being tried out to secure a superphosphoric acid by calcining, and also by the use of electric furnaces, but up to the present time the increased acid content secured is not sufficient to warrant the expense of the energy cost by the electrical process.

A ton of commercial fertilizer contains a certain percentage of potash, phosphoric acid, nitrogen, and filler. These percentages vary depending on the purpose for which the fertilizer is desired; but the filler constitutes the larger percentage, and it may be in the form of lime, water, soda, cotton seed meal, gneiss, or animal matter.

Manufacture

The manufacture of so-called commercial fertilizers is carried on by plants of various types, namely, small dry mixing plants, filler plants, combination cotton seed oil and fertilizer plants, and acid and non-acid making plants. The dry mixing plant may be operated in conjunction with a cotton seed oil mill, or entirely separate. In the majority of cases the distinct small dry mixing plant is located in the less populous sections and has most of the necessary plant food elements shipped in. The mixing is done by hand, or supplemented by a batch mixer, the difference being that in the former case the elements are placed on the floor in layers and mixed by shovels, dumped into an elevator pit, elevated to screens, and thence to the hopper and sackers. In the latter method the constituents are carried separately to the power mixer and all mixed at the same time. The batch-mixing process is conducted as follows.

The quantity of each material necessary for a ton of fertilizer is dumped separately into a pit and carried by bucket elevator, thence by chute into reel, and through a screen to hopper. The lumps that do not mesh are carried by tailing chute to a clod breaker and back to the elevator pit. The screened material leaves the hopper and enters a revolving mixer where all elements are mixed in one batch and emptied by chute into a bagging hopper and scales, and sacked in 100- and 200-lb. bags. There are different types of rotary mixers on the market, some of which are sold complete, including elevators, screens, clod breakers, hoppers, and scales.

These equipments are generally driven from a main shaft running at 200 r.p.m. The elevator shaft is driven from the screen countershaft. The mixer and clod breaker are driven by belt from the main shaft, the former operating at 165 r.p.m. and the latter at 400 r.p.m.

Where the mixing is done by hand 15 to 20 h.p. is required to run the elevator, reel, and screen. The batch, or power-mixing process requires from 30 to 35 h.p. As the period over which these plants operate is comparatively short, starting about February 1st and operating to May 1st, and intermittingly through May and June, and possibly again in the fall, some type of internal combustion engine is generally used. These plants mix about 100 tons per day.

Although this class of business is not specially desirable, some central stations have worked out a system of rates with a minimum guarantee that has proven satisfactory to both parties. The maximum demand on the average hand-mixing plant is about 15 kw. for a sustained 30-minute period with a power consumption of 1.5 to 2 kw-hrs. per ton sacked. The yearly load factor, based on 24 hours, is about 3 per cent. The batch-mixing plant as described has a maximum demand of from 20 to 30 kilowatts and a consumption of 2.5 kw-hrs. per ton sacked, with a load factor on a 24-hour basis varying from 5 per cent on the smaller plants to 12 per cent on the larger.

A number of so-called filler plants are in operation, supplying the fertilizer manufacturers with ochre, feldspar, and crushed limestone. The minerals are finely ground and utilized as dryers, and contain as well a small percentage of plant food. Filler plants generally mine decomposed feldspar, or gneiss, which runs about 5 per cent unavailable potash, that is assimilated by the soil over a period of time.

The process of getting out this type of filler consists in blasting the shale, which is then carried to the crushers by hoists or cars, after which it is passed through drying cylinders. The air for drying is heated by burning powdered coal and is forced to the drying cylinders by fans. After the product is dried it is delivered to the pulverizers and thence to the screen where it is screened to 60 mesh and conveyed to storage bins or cars and shipped in bulk.

A specific plant produces about 40,000 tons of filler or dryer per year with a power consumption of 3.3 kilowatts per ton, a 30-minute maximum demand of 75 kilowatts, and a 24-hour load factor of 20 per cent. Power cost averages about 6 cents per ton. The heaviest running is done between January 1st and May 1st, but weather conditions affect outside work and sometimes these plants get out large tonnages during good weather and accumulate considerable storage in order to supply the demand later on.

The plant referred to has the following equipment: One 25 h.p., 1200 r.p.m., squirrel cage motor operating the machine shop and coal conveyor; one 75 h.p., 900 r.p.m. squirrel cage motor operating two Clark pulverizers, conveyors and hoists; and one 25 h.p., 900 r.p.m., squirrel cage motor operating the dryer. The Clark improved anti-friction pulverizer, with a capacity of 15 tons per hour, requires 30 h.p., and the 20th Century pulverizer and screen, 20 tons per hour, requires 25 h.p. to drive.

The crushed limestone used as a filler is generally the fine screenings or by-products of crushed limestone plants, and in this case

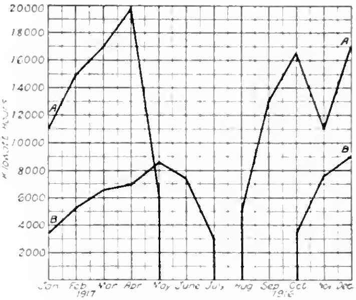

Fig. 2. Monthly Power Consumption of Typical Filler Plants

the kilowatt-hour consumption per ton is negligible.

Fig. 2 shows the kilowatt-hour consumption by months for two typical filler plants, both mining feldspar shale. By referring to the performance of these plants between May and October it will be noted that they do not cease operation at the same time; this being due to local conditions and to the fact that the fertilizer manufacturers whom they supply draw on these plants at different times to take care of their demands.

As the majority of fertilizer plants use alternating current, any mention of motors or electric power in this discussion will refer to alternating current and a-c. equipment unless otherwise noted.

Some manufacturers have complete plants, including acid chambers for the manufacture of sulphuric acid for their own need and for sale to plants that require sulphuric acid. Other plants may be complete in every detail, with the exception of acid chambers, and secure the acid from outside sources. Then, too, quite a number of plants find it more economical to dismantle or discontinue the use of their acid-making equipment, due to the fact that they may be able to purchase the acid and turn out fertilizer at a less cost per unit ton than if they maintained the lead containers at the present prices of lead acid-making equipment. The two types are generally designated as acid-making and non-acid-making plants. These facts have little or no effect on the final product, and the power engineer is only interested to the extent that the operating characteristics, power load and kilowatt-hour consumption differ for the two types of plants.

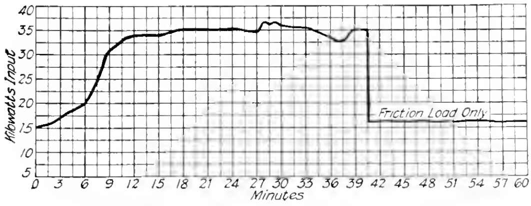

Fig. 3. One-hour Load Phosphate Rock Grinding, Operating Pratt Mill, Conveyors and Elevator

This leads up to an analysis of the various processes and the application of electric motors to the apparatus required in the manufacture of fertilizer.

Rock Grinding

The manufacture of superphosphate, or the conversion of mineral and bone phosphate, together with sulphuric acid-making, are the chief processes in the production of fertilizers. The treating of insoluble and unavailable phosphates with sulphuric acid, and changing these into soluble and available forms, is called superphosphate manufacturing, and is the basis of nearly all mixed fertilizers. In order to receive the proper impregnation of sulphuric acid the phosphate must be ground to a fine dust.

There are numerous methods and types of grinders in use. The first step is to deliver the rock to the grinding mills by belt conveyors which run back under the piles of phosphate rock. The material is dumped into bucket elevator pits and then carried up to the rock hopper, from which it falls by gravity through chutes to the grinding mills. The rock is ground to a very fine dust and screened, from 90 to 96 per cent passing through 60 mesh. It is then conveyed by bucket elevators or fans to dust bins.

The conveyors and elevators in the grinding department may be operated by individual motors, or all equipment for a complete grinding unit may be driven in a group from one motor.

In the erection of a new plant it is a comparatively simple matter to provide the grinding machinery with the proper individual motors; but for the plant that has the mechanical type of drive already installed, many problems may have to be solved before the proper motors can be determined.

The power required to drive the grinding department depends on the type of mill, the number of grinders, and type of conveying and elevating equipment. Chains, or link belts, should not be used for the main drives, as this type of drive is positive and in certain departments of the fertilizer plant a clogging up or choking in the feed is liable to occur. The belt is more flexible and has a tendency to give or slip under sudden strains, which fact, of course, affords better operating conditions than the former method of drive.

The belt conveyors which carry the rock to the elevator pits generally require from 3 to 7½ h.p., depending on the number of tons of phosphate rock delivered in an hour. These conveyors vary in width from 14 in. to 20 in. and operate at 200 ft. to 350 ft. per minute. The motors are belted to the counter-shaft and operate at 170 to 200 r.p.m. Bucket elevators require 5 to 15 h.p., depending on the quantity of material elevated per hour. The elevators usually run at a speed of 175 ft. to 250 ft. per minute, the motors being belted to the countershaft. In some plants the rock is fed into a rock crusher, the broken rock passing into a hopper and thence to elevator pits, and is elevated to the screen and distributed on an 18-in. 5-ply belt with ⅛ in. rubber covering, which delivers the rock to another screen and into the mill hopper. This equipment can be operated from the main pulverizer group machinery, but is usually driven by an individual 25 to 35 h.p. squirrel cage motor.

In the case of group drive one motor may be belted to the main line shafting. A typical group operated by 75 h.p. motor has the following equipment:

- One Pratt mill, capacity 4 to 5 tons, 90 per cent of phosphate dust passing through 60 mesh screen per hour;
- One phosphate rock conveyor, 20 ft. by 16 in.;
- One phosphate rock elevator, 45 ft. with 6 in. by 10 in. buckets using single chain drive from counter-shaft;
- One screw dust conveyor, 14 ft. by 10 in.

Friction and full-load curve-drawing charts on this mill covering a period of one hour showed an input of 36 kw. when grinding at the rate of 4 tons per hour, and energy consumption of 9 kw-hr. per ton. This chart is shown in Fig. 3. It was expected that other machinery would be added to this motor which accounts for the over-motoring of this group. The power required to drive the Pratt mill runs from 10 to 15 h.p. per ton of 90 per cent, 60 mesh dust per hour.

This mill is made in different types. For reasonably fine grinding the separation is done inside the machine, no outside separators being used, and for very fine grinding the product is separated inside and the final separation made by outside separator. These mills are furnished for either rope drive with vertical rope pulley, or belt drive with horizontal or vertical pulley.

Distinct separators are sometimes used, depending on the type of pulverizer, or grinder. These separators require from 2 h.p., when driven individually, to 5 h.p. in pairs. A pair of Newago screens are usually driven by a 5-h.p. motor and may be used for screening rock, fertilizer, bone, or cotton seed meal. Other screens requiring about the same power are the Stedman, Jeffrey, and Pratt.

The Sturtevant mill is made in several sizes and requires 10 h.p. for the 24-in. ring to 90 h.p. for the 44-in. duplex. This mill is driven by a countershaft at 290 to 310 r.p.m., with one gear reduction to the grinding ring. On a mill grinding 6 to 8 tons per hour of 90 per cent, 60 mesh dust, tests show a consumption of 10 h.p. per ton.

The Bradley mill requires approximately 50 h.p., and is constructed similarly to the Pratt mill, a vertical motor being belted to the main vertical shaft of pulverizer.

The Kent mill requires from 35 to 50 h.p., the motors being usually equipped with extended shaft for double belt drive. With all makes the amount of rock fed to the mill, the degree of fineness to which it is ground, and the condition of the rock affect the power consumption. Average conditions require about 8 to 11.5 h.p. per ton of 90 per cent, 60 mesh dust.

In the manufacture of fertilizer, as in most other industries, improvements and new processes are eagerly tried out with the hope that a better product, or a lower cost per ton, will result.

The Raymond mill embodies somewhat different features from the mills mentioned above, in that the pulverized rock or dust is elevated to the dust bin or hopper by suction, and no internal, or external screens are used. The air is admitted underneath the grinding surface taking the finished material away by air current as quickly as it is reduced by the rolls, thus keeping the mill free of fine material.

The coarse material carried up by the air current is separated from the fine, the latter being carried directly to the cyclone collector by the air current and the former being returned to the mill in a continuous stream from the edge of the revolving spider, over which a thin sheet of air at high velocity is constantly passing.

To drive the entire unit, including fan and mill, 100 to 125 h.p. is needed. Tests show a power consumption of 15 to 16 h.p. per ton of 95 per cent, 90 mesh dust.

Acidulation

The next process following the grinding and storage of the phosphate dust is to mix the dust with sulphuric acid to secure an acid phosphate which is called acidulating. As the process of manufacturing sulphuric acid is a very important one, we will discuss it in more detail later, assuming for the time being that the acid is already in the proper containers and ready for use. The quality of acid phosphate depends on the accuracy of weighing and the care taken in mixing. Approximately the same weight of 50 deg. Baume sulphuric acid is used as phosphate dust. The mixers vary from ½ ton to 2 tons, the one ton being the most popular. Nearly all of these mixers are constructed of iron throughout and are mounted in a standard having the form of a ring which encircles and supports the pan. Ball bearings are used and the pan is driven through a circumferential gear.

Many types of stirrer blades are in use, but the most common is the plow type, with the plows revolving in opposite directions. The charge of dust and acid is run into the machine where the motion of the revolving pan and stirrers thoroughly impregnates the dust with acid, causing the decomposition of the tricalcic phosphate into monocalcic phosphate. After the charge has been mixed for some 3 to 8 minutes, the discharge plug is raised by a lever from the outside, the mixture (acid phosphate) dropping directly into "hot den" storage rooms, or into automatic dump cars which convey the material to storage. These mixers have a countershaft and pulley and can be readily driven by a motor. Power requirements run from 8 h.p. on the one-ton to 12 h.p. on the two-ton mixer. A number of plants use one motor to drive mixers, car puller and conveying machinery.

A very high temperature prevails when the dust and acid are mixed, resulting in the generation of carbon dioxide, chlorine, and fluorene gases which are both obnoxious and injurious to the workman. These gases are removed by exhaust fans having flues connected directly to the top of the mixing pans and to the hot dens, thus allowing the acid phosphate to dry more quickly. As these gases pass through the flues, they are absorbed by a spray of water which is drained to retainers and used for the manufacture of by-products. The power required to operate the fans depends on local conditions, the outfit for one mixer showing a consumption of 7½ to 10 h.p. Water spray for fluorene discharge flues may be secured from a plant water tank, or small pump. The power required to operate the acidulating department therefore depends on a number of factors and the kilowatt-hour consumption per ton of acid phosphate varies materially with each plant. Figures obtained from a number of plants show a consumption as low as 5 kw-hr. per ton for coarse grinding, and as high as 20 kw-hr. per ton for very fine grinding, including the fluorene gas scrubbing equipment, and an average of 7 to 8 kw-hr. per ton for all types.

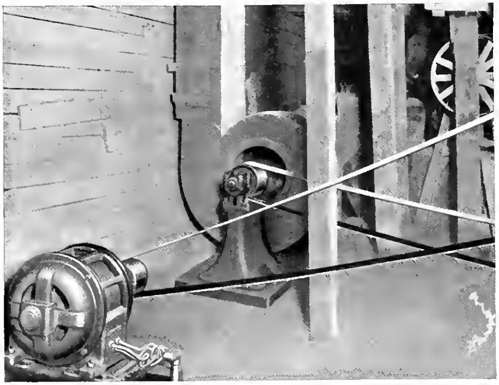

Fig. 4. Acidulating Department. 25-h.p., 1200-r.p.m. Squirrel Cage Motor Driving 1-ton Mixer, Car Puller, and Fan for Removing Chlorine Gas Fumes

Fig. 5 shows the variation by months of kilowatt-hours per ton of wet acid phosphate. The average for this plant is 11.6 kilowatt-hours per ton.

Table I shows tonnage of phosphate rock ground, and tonnage, kilowatt-hours, and cost per ton of acid phosphate made in another plant covering a period of one year. The cost per ton of acid phosphate, as indicated by this table is considerably higher than the average. This plant uses the Raymond system of pulverizing and has several fans for fluorene gas scrubbing. As claimed for the Raymond system of pulverizing, the average consumption of sulphuric acid per ton of acid phosphate is less than 50 per cent, and actually runs 39.5 per cent acid to 60.5 per cent phosphate rock.

The dump car system may be operated by an individual 15 h.p. motor, or from the acidulating group. This drive is designed for the handling of dump cars to and from any desired point in the dumping or storage shed. The drive usually consists of steel cable passing over a rubber lined sheave at one end and a plain sheave attached to an adjustable take-up at the other end, and supported at the intermediate points by idler sheaves. The drive sheave is gear-driven by a clutch shaft having two clutches mounted on it, one for direct and the other for reversed operation.

Acid Making

Sulphuric acid plays an extremely important part in the manufacture of fertilizers. At the outbreak of the European war the United States had an annual output of sulphuric acid aggregating 4,000,000 tons. The production for 1916 was 5,500,000 tons—an increase of more than thirty-five per cent.

Many acid plants closed down in the fall of 1914 because of the anticipated greatly decreased demand for fertilizer owing to the cotton situation and general economic demoralization.

After the situation had improved a number of acid plants resumed operations. The war situation created a shortage of vessels, however, and as the fertilizer industry depended on sulphur, or pyrites, which were mostly imported from Spain, the price of sulphuric acid rose rapidly. The sulphur ore shortage started the mining development in this country, and today large quantities of sulphur are being supplied from the Texas and Louisiana openings. Lump and fines pyrites are also secured from the North Carolina and Georgia mines.

Sulphuric acid may be considered a compound of sulphur, oxygen, and water. When sulphur is burned it unites with two atoms of oxygen, forming a sulphur dioxide compound. In order to form sulphuric acid. however, another atom of oxygen must be forced into this compound, giving a product known as sulphur trioxide, which unites readily with water to form sulphuric acid. The main purpose is to effect the combination of sulphur dioxide with the third atom of oxygen. In most cases in actual practice it has been found more convenient to burn pyrites instead of sulphur. Pyrites, known also as fool's gold, contains iron and sulphur, which burns as readily as coal and yields sulphur dioxide. This gas is forced by air through a series of large lead chambers, over which water or steam is sprayed. The necessary chemical actions take place at this point, and sulphuric acid is produced.

This process is carried on night and day, unless the plant has to be shut down for repairs, or owing to power stoppages affecting the fans and spray pumps.

There are two methods of burning employed. In the first method, revolving furnaces of the wedge or Herresshof type are utilized. A back-geared motor is usually used for driving.

The fines pyrites is fed in at the top through a hopper. The ore burns continuously and is carried down by revolving raker arms through a series of shelves to the slag pit. Sulphur dioxide gas is given off as the ore is burned, which is removed by a fan connected to an opening at the top of the furnace. Another opening is also provided in the bottom of the

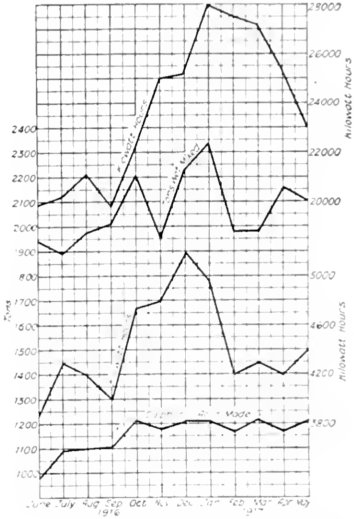

Fig. 5. Curve showing tons Wet Fertilizer mixed and tons Sulphuric Acid made for each month and power consumption per month for each operation

TABLE I

KILOWATT HOURS AND POWER COST PER TON OF PHOSPHATE GROUND AND ACID PHOSPHATE MADE

Month	Tons Rock Ground	Tons Acid Phosphate Made	Kilowatt Hours Used	Monthly Power Cost	Kw-hrs. per Ton Acid Phosphate	Cost per Ton Acid Phosphate Made
1916						
June	1,300	2,225	32,870	$357.00	14.8	$0.16
July	960	1,630	34,450	381.00	21.2	.234
Aug.			2,400	31.00		
Sept.	400	670	2,840	36.00	4.2	.053
Oct.	1,200	2.060	32,570	357.00	15.8	173
Nov.	830	1,420	23,300	257.00	16.4	.181
Dec.	1,250	2,130	40,600	440.00	19.1	.207
1917						
Jan.	2,300	3,230	44,000	470.00	13.6	.145
Feb.	2,200	3,750	62,400	660.00	16.6	.176
March	2,200	3,760	57,700	600.00	15.4	.159
April	2,150	3,660	59,000	625.00	16.1	.171
May	1,400	2,350	50,500	540.00	21.4	.230
Total for 12 Months	16,250	26,885	442,730	$4,754.00		
Average for 12 Months	1,354	2,240	36,811	396.10	16.4	177

furnace, which allows the necessary oxygen to be drawn in, to complete proper combustion. The sulphur dioxide passes through an oven charged with nitrate of soda, where it comes in contact with oxides of nitrogen, and then passes through a Glover tower. A weak acid

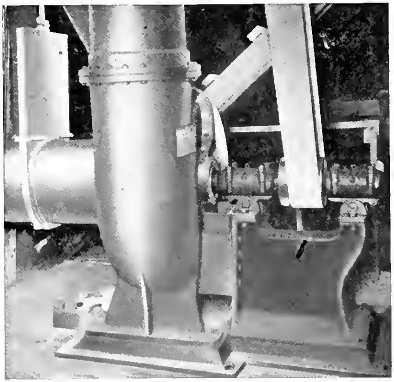

Fig. 6. Acid Making Department. Fan Removing Sulphur Dioxide from Ovens to Towers Operated by 5-h.p., 1800-r.p.m. Squirrel Cage Motor

is introduced at this stage, which tends to cool the gases before they enter a series of chambers, where a spray of water, or steam at 70 to 80 lb. pressure is used. The sulphur dioxide, oxygen, and water in these chambers combine with the aid of nitrogen trioxide which is liberated and carried to a Gay-Lussac tower for use again. Tests show that one ton of 50 deg. Baume sulphuric acid as made contains 33 per cent water.

The fans required to handle these corrosive gases have a displacement of 5000 cubic feet per minute against a 2 oz. pressure, and usually require a 5 h.p. motor. Power requirements, however, depend on local conditions, and the size of fan may vary up to 22,000 cu. ft. per minute, requiring 35 h.p Where a water spray is used instead of steam the spray pump may be of either the duplex, or centrifugal type, requiring from 5 to 15 h.p. Compressed air is used to force the acid from the storage tanks under the lead-lined chambers to storage tanks in the acidulating department. As no pump has been designed to withstand the corrosive effect of the acid, the displacement method is still in use. The compressor for this purpose usually runs from a capacity of 70 cu. ft. per min. with 15 h.p. motor to 225 cu. ft. per min., 80 to 90 lb. pressure, using a 40 h.p. motor. As a general rule the fan, pump and air compressor are furnished in duplicate in order to prevent any possibility of interruption in the process. Some plants using electric power have auxiliary gasolene engines for operating spray pump, acid fan, and air compressor.

The other method of securing sulphur dioxide gas is to burn the lump pyrites and sulphur in ovens, the gases being carried off and treated in the same way as in the furnace method; the only distinction being that no power is used other than for the fan in this method. One ton of sulphur produces about 4¾ tons of sulphuric acid.

A manufacturer operating several plants using electric power recently stated that any interruptions in the power supply were injurious in many ways, and that it was almost impossible to figure the losses from this scource. From his experience the furnaces, fans and sprays could be shut down for two hours and then started again; but that any longer interruption resulted in a serious loss of production, and a damaging effect by the corrosive gases on the lead linings. However, he has received such good all-round service from the power companies that he never thinks of installing auxiliary motive power to operate the acid-making equipment. His greatest worries are with the mechanical and not the electrical equipment.

A plant in Canada recently secured as low as 6½ cu. ft. of chamber space per pound of sulphur burned per day. The cubical content of chamber space for the average plant runs from 8 to 15 cu. ft. per pound burned. It can be readily seen, then, that the plant utilizing a lower cubical content in chamber space per pound will require less investment in lead containers with less fixed cost per ton.

Fig. 5 shows the typical variation in kilowatt-hours per month per ton of acid made on a plant turning out 30,000 tons of complete fertilizer per year. Table 2 shows the variation in power cost per ton over a period of twelve months for another plant. Results secured from tests and observations covering several years on several acid-making plants show a minimum consumption of 4 kw-hr., a maximum consumption of 18 kw-hr., and an average of 9 kw-hr. per ton of sulphuric acid made.

The plants that do not make their own acid purchase it from acid-making plants or copper companies. The acid is shipped in tank cars, and on arrival is delivered to the acid chambers by compressed air or syphon method, and forced by air up to the acid tanks in the acidulating department in the same manner as in the acid-making plant.

Bagging and Dry Mixing Department

The equipment in this department is practically the same as that used for the dry mixing plants described above, with the exception that auxiliary machinery is operated in order to grind, or put in proper shape, certain materials supplying potash, nitrogen, or ammonia to complete the proper elements which constitute a ton of fertilizer for shipment.

The number of bagging machines in any plant of course depends on the output, and may vary in number from two to ten. The smallest bagging machine requires 15 h.p. and the largest 75 h.p. In the latter case it will be found that a number of auxiliary conveyors and elevators are included in this drive, the average outfit requiring 35 h.p. The squirrel cage motor has proved very satisfactory, but in rare cases it has been found advisable to install the slip ring motor on the larger machines driving elevators and screw conveyors, as the starting conditions are very severe, especially if a power outage occurs when the machines are fully loaded.

The first step is to bring the acid phosphate from the storage to the elevator pits of the various mixing and bagging machines. After the acid phosphate in the storage has become properly dried, it is dug out by pick axes, dropped on to apron conveyors, and distributed close to the machines. These conveyors require from 3 to 7½ h.p.

Fig. 7. Two 15-h.p., 1200-r.p.m. Squirrel Cage Motors Driving two 90-cu.-ft.-per-min. Air Compressors. Elevating Sulphuric Acid

An item of interest to the power engineer is the fact that the acid phosphate can be carried from storage to the mixing and bagging machines by electric trucks. The plants which do not use the conveyor type of dis-

TABLE 11

KILOWATT HOURS AND POWER COST PER TON OF SULPHURIC ACID MADE

Month	Tons Acid Made	Kilowatt Hours Used	Kw-hrs. per Ton	Monthly Power Cost	Cost per Ton Acid Made
1916					
June	1,240	26,600	21.5	$286.00	$0.23
July	770	26,000	38.8	296.00	.385
Aug.		7,100		80.00	
Sept.	760	9,000	11.8	110.00	.145
Oct.	1,800	25,000	13.9	270.00	.15
Nov.	1,470	24,000	16.3	264.00	.18
Dec.	2,100	31,000	14.7	330.00	.157
1917					
Jan.	1,600	30,700	19.2	330.00	.206
Feb.	1,660	25,800	15.5	270.00	.162
Mar.	1,530	26,000	17.0	275.00	.18
Apr.	1,830	30,000	16.4	320.00	.175
May	1,300	21,000	16.1	210.00	.161
Total for 12 Mo.	16,060	282,200		$3,041.00	
Average for 12 Months	1,338	23,517	17.5	$253.41	$18.9

tribution have found that the introduction of these trucks has cut in half the labor cost per ton mixed. These trucks are generally of two-ton capacity. The charging outfit is installed in the shipping department. To assist in loading the electric truck an electrically operated shovel may also be used, which requires about 7½ h.p.

In addition to the machinery already mentioned for the manufacture of fertilizer, a number of plants use attrition mills for grinding leather scraps, tobacco stems, and cotton seed meal; and other mills for grinding bones, oyster shells, tankage, and fish scraps. Bone mills grind from 8 to 10 tons of tankage per hour and usually take 4 to 5 h.p. per ton. Forty to 50 h.p. motors are belted to a horizontal shaft which also has a flywheel on the opposite end.

Power tests taken on two 30-in. Foos attrition mills, single belt drive, one disk stationary and the other revolving, driven by a 30-h.p., 1200-r.p.m. squirrel cage motor, showed the following results:

	Mill No. 1.	Mill No. 2.
Each mill grinding 300 lb. of tobacco stems per hour.		
Empty	6.2 h.p. friction	6.3 h.p. friction
Loaded	24.1 h.p.	28.1 h.p.
Each mill grinding 200 lb. leather scraps per hour.		
Empty	3 h.p.	3.44 h.p.
Maximum	28 h.p.	28.3 h.p.
Average	16 h.p.	16.2 h.p.
Minimum	8 h.p.	8.5 h.p.

These attrition mills are also used for grinding Nebraska potash ore, which takes considerably less power per ton as compared to leather scraps or tobacco stems.

The materials from the various auxiliary mills and equipment are brought to the various bagging and dry mixers by barrows or conveyors, and the proper quantity of each element is carefully weighed so that the right percentage of potash, ammonia, or other constituent is included in each ton of finished product.

Mixing, bagging, and shipping consume from 0.8 kw-hr. per ton for the plant delivering goods direct from bagging machine to freight cars by hand truck, to 2.2 kw-hr. per ton where power apparatus is used to convey the finished product to the cars. The consumption per ton on five plants shows an average of 1 kw-hr. per ton over a period of several years. Table III shows costs and kilowatt-hour consumption per ton for mixing, bagging, and shipping on an up-to-date plant.*

In figuring the total kilowatt-hours consumed per ton, it will be noted that considerable difference exists between the sum of the individual kilowatt-hours consumed per ton per department, and the average consumption per kilowatt-hour per ton of goods shipped.

This difference is due to the fact that in the final process of mixing and bagging considerable tonnage of other materials is added with

TABLE III

KILOWATT HOURS AND POWER COST PER TON OF FERTILIZER MIXED AND BAGGED

Month	Tons Mixed Bagged	Kilowatt Hours Used	Kw-hrs. per Ton	Monthly Power Cost	Cost per Ton
1916					
June	100	10,500	105	$115.00	$1.15
July	50	1,250	25	10.00	.20
Aug.	300	900	3	11.00	.0366
Sept.	1,000	1,750	1.75	22.00	.0220
Oct.	1,600	1,400	.87	70.00	.0437
Nov.	800	12,500	15.6	140.00	.1750
Dec.	840	2,200	2.62	24.00	.0285
1917					
Jan.	3,500	8,300	2.37	90.00	.0257
Feb.	7,800	19,300	2.46	200.00	.0256
Mar.	14,300	9,300	.65	110.00	.0077
April	7,800	7,700	.98	82.00	.0105
May	700	7,100	1.02	75.00	.1070
Total for 12 Mo.	38,790	82,200		$949.00	
Average for 12 Months	3,232	6,850	2.12	79.01	.0245

* The power cost per ton in all departments will vary more or less from month to month, but not to the extent that it does in the shipping department. The wide variation in cost for June, July, and May, as shown in this table, is due to the fact that in the dull months auxiliary machinery is sometimes operated which consumes power while a small tonnage is bagged.

the acid phosphate to produce a unit ton of the proper formulae, thereby increasing the gross tonnage while the total kilowatt-hours consumed remains the same.

Percentage of power requirements for each department for plants making acid:

	A	B	C	D	E
Rock Grinding and Wet Mixing......	44.5	37.5	41	44.5	45.0
Acid Making.......	39.5	35.5	40	39.0	40.0
Mixing, Bagging, and Shipping.........	10	19	12	12	9
Lighting and miscellaneous..........	6	8	7	4.5	6
Total	100	100	100	100	100

Figures obtained from a plant using electric power and buying acid show that 81 per cent of the total power was required for the rock grinding and acidulating department. Included in this percentage is the power used for operating the air compressor which elevates the acid from the storage tanks to the acid phosphate mixing machines. In this instance 12,770 tons of acid phosphate were made; the air compressor showing a consumption of 1 kw-hr. per ton. The commercial department of this plant, which includes dry mixing, bagging, and shipping, turned out 19,150 unit tons of complete fertilizer, and consumed the balance, or 19 per cent, of the total power. As a general rule, the plants securing acid from an outside source divide the power consumption under these two heads. Each plant uses its own methods of charging power percentages to the various departments, some manufacturers distributing general expenses that cannot be readily ascertained over the other departments; this method, of course, has a tendency to swell other department percentages.

When electric drive is installed each department can be metered and reliable manufacturing cost data thus secured.

Comparative Power Cost

The amount to be saved, or the return on the investment necessary to change over the mechanically or electrically driven plant to central station service, depends of course on a number of local factors, such as the amount of the investment for electric equipment, price of fuel, and labor conditions. If the present prices of coal are taken into account there is really no need for comparative figures, as a glance at the plant's operating costs will immediately show there is no question but that purchased service is more economical; and if the proper equipment could be installed in a reasonable time, the saving of purchased service over isolated operation would pay for the new equipment in a comparatively short time.

This large saving is further illustrated by the following average departmental power costs covering the past six years, as compared to costs for the fiscal year ending June 23, 1917, on an isolated electrically operated plant utilizing up-to-date direct-current equipment.

	Cost per Ton, 6 Yr. Average Cents	Cost per Ton Year Ending June, 1917 Cents	Tons of Material Manufactured Year Ending June, 1917
Acid made...........	$0.3377	$0.601	20,100
Acid Phosphate made.	.2478	.413	24,150
Dry Mixed, bagged and shipped.......	.0510	.072	34,540
Total	$0.6365	$1.086	

These power costs show an increase of over seventy per cent for the last fiscal year's operation as compared with the six-year average. While this plant was securing coal at $2.50 per ton laid down at the boilers, it was a difficult matter to interest the management in purchased power, even though a saving could be effected by adopting central station service. But recent fuel conditions have resulted in the management deciding to invest approximately $20,000 for 550-volt alternating-current motors, salvaging the entire direct current motors and power plant equipment.

The following comparative power costs on a mechanical driven plant which was later electrified is especially interesting, as it required about five years of missionary work to convince the management that electric drive should be used.

Type of Service	Fiscal Year Ending	Power Cost	Tons Complete Goods Shipped	Power Cost per Ton	Cost of Coal per Ton
Mechanical	1915	$4590	12,100	$0.3793	$2.45
Mechanical	1916	5500	11,611	0.4741	2.70
Electric	1917	3182	11,440	0.2780	

For the fiscal year ending June 1917, the departmental electric power costs were as follows:

Acid phosphate made
8.095 tons at 17.29 cents per ton
Sulphuric acid made.
5,800 tons at 20.38 cents per ton
Dry mixing, screening and bagging
11,440 tons at 5.26 cents per ton

The saving through the use of electric power for 1917 over mechanical drive for 1916 shows a gross return of over thirty per cent on the investment of $6,300 required to equip the plant electrically.

Fertilizer plants as a rule demand power at about the same season as will be observed by referring to Fig. 8. Curve A shows the total kilowatt-hours used by one plant, and curve B the average monthly consumption of seven plants. These curves follow each other very closely from month to month. A typical 24-hour load curve is shown in Fig. 9.

Motor Equipment

A number of plants are using 220 volts and a few 2300 volts, but experience has proven that 440 or 550 volts works out to the best advantage. While 2300 volts admits of smaller copper, the wiring and protective features are more complicated, and then, too, the insulation of stator coils is a serious problem, as the fumes generated in fertilizer plants are very injurious to the motor windings; 2300-volt motors, therefore, are less desirable for this reason. Motor windings of 220 volts are not so susceptible to insulation break-downs due to these fumes, but where large motors are scattered over wide areas the cost of heavy copper must be considered. It appears, then, that the 550-volt motor will give the best all-round service.

Fig. 8. Monthly power consumption of a Specific Fertilizer Plant and the average of seven plants

While it has been found that the windings on the standard 550-volt motor will stand up reasonably well in the bagging and grinding departments, it is recommended that all motor windings be specially impregnated to withstand the fumes, especially those motors

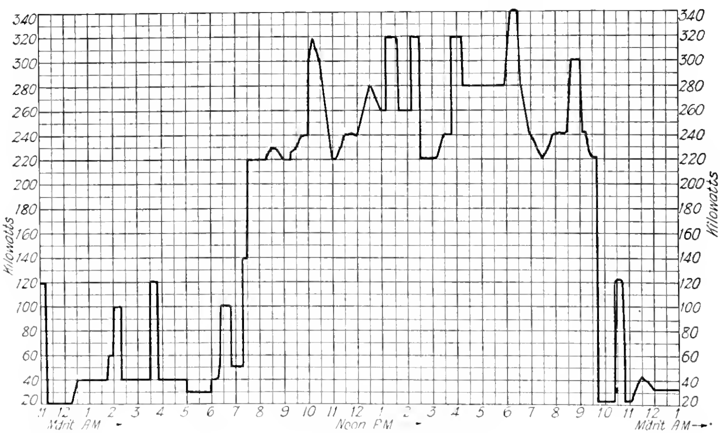

Fig. 9. Typical Load Curve of a Fertilizer Plant

driving fans removing corrosive gases, and operating the mixing machinery in the acid-ualting department. All motors should be equipped with dust-proof bearing, as the phosphate and other dusts contain acid, and permeate everything within a considerable distance of the machines. It is not necessary to have specially treated coils in motors operating pumps and air compressors in detached buildings. Motors should be equipped with overload and no-voltage release attachments, and be installed in a foolproof manner, as the labor handling the electric equipment from day to day is usually unskilled.

Wiring

The type of wiring to be used in any plant will, of course, depend on the location, city ordnances, and underwriters' requirements. Three-conductor lead-covered cable, properly supported or covered with wooden moulding or galvanized conduit, is used in some plants. The most popular method, however, is to run heavy main and branch lines of triple braid weather-proof wire on poles or attached to buildings, entering the buildings where service is required with 30 per cent rubber-covered wire treated with acid-proof paint. This type of wiring, installed in 1910-1911 in several plants, is in excellent condition today.

Lighting

From the writer's experience, there is probably no type of plant so poorly lighted as the average mechanically driven or isolated electrically driven fertilizer factory. The illumination for the yards may be in the form of the antiquated open arc; while the interior is usually lighted by carbon lamps covered with dust, no attention being paid to renewals, efficiency, or proper illumination.

The constant hammering of Mazda lamp publicity, however, is having its effect, and of late a slight improvement is noted. A certain plant manager states that fewer accidents occur, production is increased, and less confusion results since proper illumination of his plant has been provided.

The power engineer can spend time very advantageously in studying illumination, knowing that any improvement in this respect will do much to crystallize opinion in favor of purchased service. The intensity of illumination required for these plants varies from 1 to 3 foot-candles, depending on the distribution of machinery and materials.

In changing over a plant to central station service it is seldom necessary to change the existing wiring, with probably the exception of re-arranging the lighting switchboard. Single-phase transformers in capacity equivalent to 3 to 4 per cent of the maximum demand are usually sufficient.

TABLE IV

OPERATING CHARACTERISTICS OF SEVEN FERTILIZER PLANTS 1916-1917

	A	B	C	D	E	F	G
Capacity in tons per year	100,000	20,000	60,000	30,000	20,000	40,000	25,000
Manufacturing, or buying acid	mfg.	buying	mfg.	buying	mfg.	mfg.	buying
Connected horse power	550	240	500	235	230	840	245
Maximum kilowatt demand (30 min.)	300	60	320	60	150	350	80
Maximum mothly consumption	61,000	23,000	107,500	26,300	26,600	110 000	22,500
Average monthly consumption	43,500	11,300	68,200	13,600	18,000	58,200	17,300
Minimum monthly consumption	16,000	1,000	10,500	5,140	3,700	20,000	12,600
Load Factor—8760 hrs. per year	20%	25.8%	29.2%	31%	16.5%	22.6%	29.8%
Fire Pump gal. per min.	1,000	750	1,000	750	500	1,000	750
Kw-hrs. per ton acid phosphate	11	11 4	16	13	11.7	14	10
Kw-hrs. per ton acid made	10		17.8		10	8	
Kw-hrs. per ton, mixed and bagging	1.65	.2	2.5	1.5	1.3	3	1.95

No calculations have been made for the number of kilowatt-hours consumed per ton of goods shipped, as this tonnage shows a wide variation due to the elements that are added to the acid phosphate to complete a unit ton.

Advantage of Electric Drive

The advantages to be derived from the use of electric motors and central station service may be summed up under the heads of efficiency, utilization, and production. The electrically operated plant with motors properly distributed can manufacture a ton of fertilizer more economically than the mechanically operated plant with its attending long line shafts. If an outside source of power is available, boilers, feed water heaters, steam engines, generators, and other equipment chargeable to isolated generation can be salvaged; or if a new plant is being erected, this investment required for power plant can be directed to more useful channels, thereby lessening the fixed charges and permitting a lower cost per unit of product. From a purely dollars and cents comparison, with fuel at normal prices, electric power at a fair rate is decidedly more economical than steam power.

Individual motors permit the placing of machines wherever they can be most efficiently used, eliminate friction losses of line shafting, and allow the machines to be brought closer to the work. During certain seasons of the year only certain departments are required to operate; therefore, by using motors to drive this section, power consumption is in proportion to the work done. Then, too, special electrically operated labor-saving devices may be used, such as electric trucks, shovels, cranes, and car systems.

Each department may also be metered, which will indicate the exact power cost per ton of material produced.

Water Power—Our Electrochemical Salvation

By C. A. Winder

Member of A.E.Ch.S. and N.E.L.A. Joint Committee on Power for the Electrochemical Industry

Few of us are aware of the great number of substances that are dependent upon electrochemical methods for quantity production. Some of our most important industrial materials are among them. To produce these substances enormous quantities of electric power are required, which fact indicates water power as the only economical source of energy; and therefore we are not surprised to find the center of this industry located in the vicinity of Niagara Falls. The author undertakes to show that at least 50 per cent of the water now passing over Niagara Falls could be quickly and cheaply diverted for power purposes, without in anyway detracting from the natural beauties of the cataract, and that in view of the serious shortage in coal and the urgent need of electrochemical products by the government, it is the duty of Congress to enact legislation at once which will make available the great quantity of energy that is now being wasted.—Editor.

Now that the visible coal supply is rapidly diminishing and water power stands largely undeveloped, what chance has the electrochemist—the greatest user of power—to expand to meet the increasing demands of the present day? The electrochemical industry is vital to the success of the great world war; that water power is vital to this industry will be shown in the following paragraphs.

A consideration of the facts will be facilitated by a division of the electrochemical industry into three classes:

1. Those that cannot be moved from the country by any means and will stay regardless of the cost of power.
2. Those that exist at present and to a greater or lesser extent depend upon natural conditions for their existence and growth.
3. Those that have no footing in this country or are not as yet in existence.

The first class includes the industries of copper, zinc, and rare-metal refining and electric-steel production and is, perhaps, as a group, the largest user of power. The second class includes the following industries in the order of their importance: Aluminum, ferro-alloys, carbide, artificial abrasives, alkali, chlorine, phosphorus, sodium, carbon disulphide, graphite, and similar products. The third class would then include the nitrogen-fixation industry and possibly others for making products we know little or nothing of at this time, there being no power consumed within our boundaries for products of this class.

It is in the industries of the second class that we are mainly interested at present. Their products are absolutely indispensable to the arts and manufactures. For instance, without ferro-alloy and aluminum a 2200-lb. automobile would weigh more than 4000 lb. Without the latest grinding devices made of artificial abrasives and high-speed tool steel, a factory producing 500 cars a day could not produce 100. Without caustic and bleach, the latest improvements in the textile and paper industries would be impossible. Chlorine is used in purifying the water supply of a thousand cities and every camp of the American Army, is employed in the manufacture of intermediates for dyes, is greatly used as a poisonous gas in modern warfare, and is consumed in enormous quantities in the manufacture of high explosives. Without chlorates and phosphorus we would lack matches and perhaps have to return to the "flint-and-steel" age. In fact, practically every industry is in some way dependent upon electrochemical products.

Enormous quantities of power are required in the production of these electrochemical substances. Single plants in some communities consume sufficient electrical power to furnish the domestic needs of a city of half a million. Before the great world war, this industry as a whole required close to half a million horse power. These requirements will continue during the present period, together with an enormous increase due to the war. It is this war demand that is the serious consideration now.

Not a shell is made that is not shaped by electrically made abrasives. The electric furnace from which the armor plates are poured uses electrodes made from coal by the aid of electric power, the resisting power of this same steel is given by electrically made ferro-alloys. Merchant vessels are now using smoke buoys in which quantities of phosphorus and other electrochemical products are burned emitting large quantities of smoke to protect the boat from the submarine. High explosives utilize chlorine, aeroplanes aluminum, and observation balloons hydrogen produced by the aid of silicon. In fact, every tool of the modern army is in some way dependent upon the electrochemical industry. Furthermore, our military preparations are already calling for very considerable quantities of many electrochemical products for which ordinary industrial demands are small or non-existent; and therefore these products were not produced at all or were produced in extremely small quantities. The increased demand for our vast army will be enormous. England, for instance, always a larger user of sulphuric acid, increased its demand fifteen times normal since the beginning of the war.

Where will this important industry obtain the power necessary to meet this vast demand for its product? Electric power enters into the cost of these products in amounts varying from two per cent to sixty per cent. The cost of ferro silicon, for example, is about fifty per cent power; hence power cost must be kept at a minimum. It must be kept at a minimum because we are in direct competition with foreign countries where the Governments insist on a complete development of the water power resources.

The two principal sources of power are coal and water. Daily we read headlines complaining of the "Shortage of Fuel." The

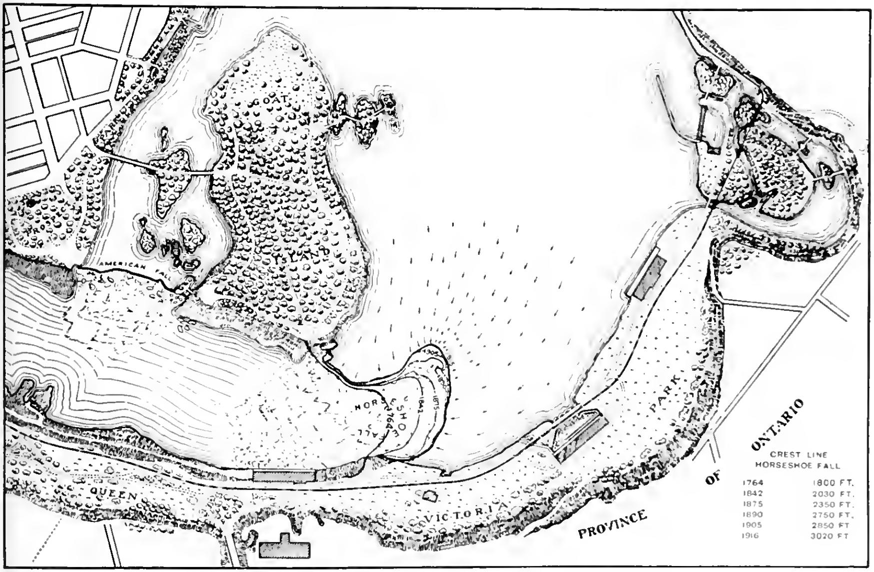

Fig. 1. Map showing the Comparatively Rapid Recession of the Horseshoe Falls of Niagara

most optimistic prognosticators tell us that the coal mines will disgorge but little over their usual amount this year. The decreased labor supply is not the only cause of the shortage. It is well known that every ton of steel requires a ton of coal in its manufacture.

Fig. 2. Photograph of the Horseshoe Falls Taken in 1870

The production of steel is without precedent and so is industry's consumption of coal. Our national effort should be to prevent additional uses of coal and, in fact, to diminish the domestic consumption in favor of the steel industry. Even if it were possible to obtain coal at prices permitting steam-electric developments, the apparatus for this purpose could not be obtained in less than two to three years. The war program of this country is such that the total capacity of the manufacturers building this class of apparatus has been requisitioned for that length of time which may even be extended. The shortage-of-power menace must be eliminated in far less time than that in order to forestall a desperately serious embarrassment in the carrying out of our war program. Therefore, we cannot look to steam to solve the power problem. Evidently our only lasting salvation is in water power.

Water power can be divided into two zones. Western and Eastern. The bulk of the Eastern water power is located at Niagara Falls, a potential possibility of perhaps six million horse power, three million available without affecting its scenic grandeur. Exponents of Western power have proclaimed; "If there is a shortage of power in the East, come to the West where there are some thirteen million horse power undeveloped at the present time." This power could be developed at a cost to permit a selling price equivalent to Niagara power some five or ten years ago. Experts state that for the manufacture of aluminum for instance, Western power, three thousand miles from the center of gravity of the aluminum market, must sell at $8 a horse power year in order to compete with $20 power near the market's center of gravity. In other words, a three-thousand-mile haul will consume in freight charges $12 per unit of aluminum manufactured by a horse power year. Aluminum consumes the maximum amount of power per pound of any of the electrochemical products. The next in order are artificial abrasives, then ferro-alloys, sodium chlorate, and phosphorus. These would have to be subsidized varying from $40 to $60 a horse power year. Caustic soda or potash, being the smallest consumer of power per unit of weight, would be the most affected by long freight hauls. The power company would have to pay the caustic manufacturer $300 per horse power year to locate three thousand miles from his center of distribution. The reason for this is that it requires twelve times as much power to make a pound of aluminum as it does to make a pound of caustic. The power consideration, therefore, is only one-twelfth the value in caustic manufacture that it is in aluminum manufacture or the freight increment twelve times the value in caustic that it is in aluminum.

How well are these conditions borne out by facts? Aluminum is manufactured entirely in the East, very near its center of gravity of distribution. Caustic chlorine, or chlorate, and like products which are used in the paper and textile industries are fairly well concentrated in the Eastern states. A small quantity of electrolytic caustic soda and chlorine is manufactured in the West but this is for local consumption only, and absolutely proves that it would be competitively impossible to ship caustic from the East to the Pacific coast for less than $300 per unit manufactured by a horse power year. The Western caustic manufacturer can never compete in the Eastern market nor can the East compete in the West. The freight haul is a very effective barrier. Thus the Western water power can never successfully assist the electrochemists in meeting the increased war demands. That power is limited until local markets develop to the refining of metals and the electrification of local railways or domestic uses, and these should be developed to the full extent of those requirements.

The water powers of the East will, therefore, have to be harnessed to meet this demand. Furthermore, it must be at those sites that can be developed the quickest and cheapest. Without question Niagara Falls fulfills these requirements: *first*, because power there can be developed without the use of large and expensive dams, and *second*, existing power companies can enlarge their present plants, intakes, and transmission lines before a new corporation would be able to secure the necessary right-of-ways. Furthermore, Niagara Falls is ideally located geographically—practically at the center of distribution of the entire electrochemical industry. Added to all of these is the one real big fact, that the electrochemical industry is already located there and it is an easier matter to increase its capacity than to establish new plants in localities where the labor is uneducated as to its requirements. Railroad facilities are excellent and water transportation available. Nature seems to have endowed Niagara Falls with all those qualifications that would build up this industry. It was that very fact that caused electrochemistry to be born there.

The electrochemical industries at Niagara Falls consumed almost all of the power developed on the American side (approximately 250,000 horse power) plus approximately 150,000 horse power imported from Canada before the outbreak of the war. Owing to the increased activities on the Canadian side, the Canadian Government has found it necessary to exercise certain rights which it retained and, in consequence, a large percentage of the power coming to this country from Canada has been cut off. The American industries at the Falls find themselves in the predicament of having installed equipment but no power to operate it. At the present time, it is doubtful if seventy per cent of the installed equipment at Niagara Falls is in operation. In other words, the plants are not turning out as much today as they were previous to the war. It was found necessary in Buffalo, but twenty miles away, to build a steam plant of 120,000 horse power. This being a public service corporation, it was necessary to produce power regardless of the cost; but when a mobile industry is affected, there is nothing for it to do but move and this is happening. Additions to a large artificial abrasive corporation are being built at Shawinigan Falls in Canada. A large portion of the output of its Niagara Falls plant has been transferred to the Canadian plant, Niagara Falls, Ont. A large percentage of another abrasive company's output is coming from its Canadian plant. Practically no carbide at all is manufactured in America, the industry having been transferred to Canada. Such conditions complete the vicious circle of increasing the demand for power on the Canadian side which

Fig. 3. Recent Photograph of the Horseshoe Falls Taken from Approximately the Same Viewpoint as that of Fig. 2

the Canadian Government sees fit to supply, thereby taking power from the American side and leaving more plants destitute with only one thing to do—emigrate to the opposite side of the border. In a short time, all our electrochemical industries may be expatriated. One of them is going so far as to build an enormous plant in Norway because the water haul from Norway to New York is an inconsiderable feature when considering the fact that power can be obtained in Norway at one-half its cost in America, due to a constructive policy of water power development on the part of the Norwegian Government together with certain natural conveniences possessed only by a few of the American water power sites.

The best hydraulic talent in America advises us that it is possible to develop at Niagara Falls three million additional horse power without, in the least, affecting the scenic grandeur of the most wonderful cataract in the world. By the proper location of submerged dams about two or three thousand feet above the crest of the Falls, the water of the river could be evenly distributed over the crest of both the American and Horseshoe Falls. This would stop the rapid deterioration of the Horseshoe Falls which has been brought about by the concentration of large quantities of water at the center of the Horseshoe. The crest of this fall is moving back at the rate of approximately seven feet a year. The total length of the Horseshoe Falls in 1842 was two thousand thirty feet which has now increased to about three thousand twenty feet. At the present rate of erosion the Horseshoe Falls will be completely eliminated in the next two or three generations and we shall have nothing but a rapids to replace them. The installation of the above-mentioned dams then would permit of the use of fifty or sixty per cent of the water, and by spreading the balance of the water over the entire cascade, and with a much smaller amount of water produce a scenic effect equal in grandeur and greater in extent than the present one.

Fig. 4. General View of Niagara Falls

To develop this power would furthermore assist in the conservation of coal, which is now a very serious matter. Engineers have calculated that three million horse power developed at Niagara Falls would save for posterity a hundred tons of coal per minute or fifty-two million tons of coal per year, sufficient to change the situation from a shortage to a surplus in the coal industry. Furthermore, it would assist in relieving the freight car shortage, releasing sixty thousand cars for use elsewhere, thereby changing the situation again from a shortage to a surplus.

The United States is now training over a million men and will perhaps train millions more to be sent to France. These men will require guns, shells, powder, gases, and all other accouterments in enormous quantities to successfully prosecute their duties. To supply the basic material required to fill this demand will require enormous quantities of power but the supply of power is not here, and worse, it is not a supply that can be furnished on a day's notice. It would take over a year to develop any considerable quantity of power at Niagara Falls and perhaps nothing large could be done even in this time.

The beauties of the cataract will not be sacrificed in the development of the power mentioned. Government engineers under the direction of the War Department have shown that but five per cent of the water of the entire river passes over the American Falls. All are agreed that the spectacle is equal to the Horseshoe Falls as to beauty. As the span of the Horseshoe Falls is but three times that of the American Falls, it is a self-evident fact that fifteen per cent of the river would create a Horseshoe Falls spectacle in every way equal to the American Falls. In other words, only twenty per cent of the water is needed to perpetuate this scenic wonder. If this be the case, fifty per cent of the water falling over this precipice certainly allows a safe margin.

It has been shown that the Electrochemical Industry is essential to the winning of the war. It has been shown also that the development of water power, particularly in the East, is necessary to the proper development of the electrochemical industry. It is essential, therefore, that the people at large interest themselves enough in this desperate situation to put themselves on record with their representatives at Washington recommending that constructive water power legislation be enacted at the next Congressional assembly. This last feature is necessary inasmuch as Congress legislates in accordance with the wishes of the people and it is therefore desirable that they express themselves in favor of such legislation so as to expedite this matter and avoid an embarrassing situation for our Government.

Fig. 5. View of the American Falls of Niagara

Methods for More Efficiently Utilizing Our Fuel Resources

PART XII. PULVERIZED COAL AND ITS FUTURE*

By H. G. Barnhurst

Chief Engineer, Fuller Engineering Company

Hydroelectric power developments and the establishment of large steam-electric central stations, which distribute energy electrically, have done much to eliminate crude and wasteful methods of burning coal. Many power stations, however, still depend upon the skill of the fireman for the efficient use of the fuel. The burning of coal in pulverized form offers an effective remedy, and puts coal on an equality with liquid and gaseous fuels in these respects. A list of previous installments of this series is given at the bottom of page 123.—Editor.

Oil and gas are the ideal natural fuels. The increase in the price of oil has made its use as a fuel practically prohibitive. The natural gas supply is rapidly being exhausted. It is very important, therefore, that we find some fuel to take the place of oil and gas; a fuel which can be burned under conditions permitting close regulation, eliminating to a great extent the human equation.

The Most Efficient Methods Must be Used for Burning Coal

The increased demand for fuel, due to the present unusual conditions and to the partial exhaustion of the sources of supply of oil and natural gas, has forced the Government to establish the prices at which coal shall be sold. These prices are considerably higher than the average prices for past years, and it has become necessary for manufacturers and others to investigate methods by which the highest possible efficiency can be attained in the absorption of heat from burning coal.

It can be safely stated that between 30 per cent and 40 per cent of the coal which is now being mined is practically wasted by careless handling and burning, under conditions not conducive to high economy.

A large number of boilers are being installed with furnaces improperly designed for obtaining the best results. A great many of these boilers have been installed with practically no consideration given to what the operating conditions would be after the boilers were in use; what kind of fuel was to be used, and the rating at which they would have to operate.

The same statement can safely be made in reference to a great many metallurgical furnaces. A large number of these furnaces have been designed and installed along lines laid down by our predecessors and too little attention has been given to the subject of fuel economy.

The same statement applies to locomotives and steamships.

Today, the land is covered with smoking chimneys, a condition which, though indicative of a prosperous condition, is, at the same time, a sign of improper installation or inefficient operation. There is no question but that the human element is responsible to a great extent for the poor results obtained, particularly in the case where coal is fired by hand.

If a highly efficient method of burning coal is available, it would seem that it is only a question of time before the public will demand that those responsible for the present smoky and wasteful conditions take active measures of adopting it, so that the smoke and soot may be eliminated.

It is also of the utmost importance that fuel be burned properly. The labor situation is such that it is impossible to obtain a sufficient number of mine operators to supply the present unusual demands. There is also a shortage of labor affecting a large number of our industries, which, in order to keep up their production, must be replaced by some mechanical means which will give the same if not better results, and thus ease the condition. There is no doubt that this labor situation will be critical for years to come and will have its effect on the fuel situation.

Large quantities of fuel are lost today through wasteful handling and burning. Eight million to ten million tons are annually put back into the anthracite mines to fill up old workings. This fuel has a high heat value and the only reason for this waste is that the coal is too fine to burn on grates. There are

* From a paper read by the author at a joint meeting of the Engineers' Society of Northwestern Pennsylvania and the Erie Section of the American Society of Mechanical Engineers, at Erie, Pa., November 13, 1917.

large deposits of coke breeze in the coking districts; this product is the result of a screening operation in which the softer particles of uncoked coal are separated. There are enormous deposits of low-grade coal scattered over our vast country, some of which have certain characteristics which prevent its being used with any reasonable degree of economy on stokers or on grates.

Pulverized Coal

The present status of the development and use of pulverized coal indicates that the future extended applications and use of this fuel will have a materially remedial influence in correcting the conditions which have been described.

Pulverized coal is coal which is properly dried, crushed, and pulverized so that the product contains the highest percentage of impalpable powder. Merely powdering the coal does not fulfill the requirements. Coal must be pulverized so that at least 95 per cent will pass through a 100-mesh sieve having 10,000 openings to the square inch, or in terms of dimension 95 per cent must be less than 1-200 of an inch cube.

The average engineer does not fully realize how fine it is possible to reduce coal today by pulverization. The proper degree of fineness depends upon the type of machine used. To give a high percentage of flour or impalpable powder in the product the pulverizer must have a mortar and pestle action which scours the particles and produces a fineness which can not be obtained by any other method.

The finer the coal is pulverized the more efficiently it can be burned and the more readily it will be diffused when mixed with combustion air and fed into the furnace. A cubic inch of coal pulverized so that 95 per cent will pass through a 100-mesh sieve will contain over two hundred million particles, none of which will be greater than one-hundredth of an inch cube, and a large percentage will be less than one six-hundredth of an inch cube. A cubic inch of coal has a superficial area of six square inches, but the combined area of these multitudes of small particles shows that when the coal is ground to the previously mentioned degree of fineness, the superficial area will increase to nearly 30 square feet, or an increase in area of approximately 700 times. This increase in area permits perfect and instantaneous combustion. One of the reasons for fine grinding is that the rapidity of burning depends directly upon the surface exposure.

Applications of Pulverized Coal

The successful use of pulverized coal was originally developed in the cement industry to replace the more expensive oil. Pulverizing machines were also brought to their present high state of development in this industry. More than ninety million barrels of Portland cement are burned with pulverized coal annually.

Recent developments in the application of pulverized coal to various kinds of furnaces have shown such marked economy over previous methods, that this fuel, now that it is better understood, will become more widely used.

The consumption of pulverized coal today in the manufacture of cement, in the iron and steel industry, in the production of copper, and for power purposes, is approximately as follows:

In the manufacture of cement, six million tons.

In the iron and steel industry, two million tons.

In the production of copper, one and one-half million tons.

In the generation of power, one hundred to two hundred thousand tons.

This shows that nearly ten million tons of pulverized coal is being used in the United States annually.

In addition to these applications, the development of pulverized coal for use on locomotives is now under way. Furthermore, the conditions for burning pulverized coal on the Great Lakes vessels are ideal. Pulverizing plants can be located at each port so that a supply can at all times be readily obtained.

It will be noticed that the quantity of pulverized coal used for power purposes is somewhat small. This is due primarily to former conditions under which coal could be obtained at low cost, and also to the fact that early pulverized coal experiments were not entirely satisfactory. Either the coal was not properly dried, or was poorly pulverized, and there was practically no control of the air supply. Furthermore, it was burned in furnaces designed and constructed for burning lump coal.

These facts show that the use of pulverized coal has gone far beyond the experimental stage, but there will be some development work necessary in its application to new operations. However, the ability to prepare, handle, and deliver the pulverized coal to the furnaces is beyond question, as there are hundreds of coal-pulverizing plants now operating satisfactorily throughout the country.

Conditions to be Observed in Burning

During the last few years a great deal of study and experimental work has been done, and it has been discovered that there are important conditions which must be observed if satisfactory results are to be obtained. This is true in connection with the use of pulverized coal for boilers, and in metallurgical furnaces. Favorable conditions are easily obtained. Furnace proportion is the most important. Destructive conditions and improper combustion are usually the result of trying to burn too much coal in a limited space. High surface velocities create erosion; and erosion means destruction.

Each pound of coal requires a given percentage of air to complete its combustion. The products of combustion for each pound of coal burned occupy a given volume at a given temperature. There are limitations, therefore, to the quantity of coal that can be burned in a given size of furnace, and the feeding equipment should permit positive control so that it will be impossible to feed more coal into the furnace than can be properly taken care of.

The limit to the surface velocity has just been pointed out as one of the conditions which must be considered. There is another condition of equal importance; the time element. Ordinary bituminous coal is composed of two principal combustible constituents—volatile hydro-carbons and fixed carbon. The volatile constituents are distilled earlier and burned with great rapidity; the fixed carbon takes a slightly longer time to ignite, hence the highest temperatures are not always reached in the zone where the hydro-carbons are burned, but are developed usually at the point where the fixed carbon is consumed. This point is some distance from the point of entrance, hence the furnace must be properly designed not only to prevent erosion, but also to assure perfect combustion.

Pulverized coal is applicable to any operation where heat is required, except where the ash of the coal might be detrimental to the material being heated.

It is not always practical to burn pulverized coal in the same compartment or furnace with the material. The charge of material to be treated naturally absorbs heat and, in certain cases, it may absorb it with too great rapidity thus interfering with proper combustion. In cases like this a separate chamber should be provided in order that the combustion may be thoroughly completed, allowing only the products of combustion to come in contact with the material being treated.

Advantages of Pulverized Coal

There is a thorough distribution of heat throughout furnaces using pulverized coal which reduces the necessity of over-firing. There is ordinarily no concentrated effect which is the most desirable condition for efficient operation in connection with boilers and heating furnaces, etc. A concentrated effect can be obtained, however, if desired.

There are distinct advantages obtained by the use of this fuel. Its feed can be regulated just as easily as can oil or gas. The intensity of its combustion is under absolute control, for its intensity depends directly upon the percentage of air mixed with the coal. Any sort of flame can be obtained, either oxidizing or reducing. In fact, for some operations it is found that the loss due to oxidation has been materially reduced as compared with oil firing.

Pulverizing does not change the nature of the coal. Its form, however, is changed to a certain extent in pulverizing it; viz., from a solid fuel into one having liquid properties. As the coal is pulverized it is mixed with air, and when handled in conveyors it flows like water; when fed to the furnaces it resembles a gas, and the furnaces must be designed to burn a gaseous mixture.

Summary of Advantages

1. Pulverized coal solves the clinkering problem.
2. Pulverized coal is smokeless.
3. A lower percentage of excess air need be used thereby reducing the stack losses.
4. All the combustible in the coal is completely consumed, eliminating loss in the ash.
5. Flexibility of operation permits quick adjustment to suit any condition of underload or overload.
6. In case of accident, the fuel supply may be shut off instantly.
7. It is possible to burn coals of almost any grade in pulverized form. Some grades such as lignite, however, require larger capacity driers.
8. Coal can be readily burned in pulverized form regardless of the percentage of ash.
9. Pulverized coal can be prepared for a reasonable figure, ranging from 60

cents down to 20 cents per net ton. This cost is dependent strictly upon the quantity of coal handled and the moisture content of the coal as received.

10. Low cost of installation in power plants as compared with other means of firing, particularly in plants having 3000 or more boiler horse power.
11. By its use in open-hearth furnaces in place of producer gas, a saving of 30 per cent of fuel will be obtained. Where the installation is for three or more furnaces of 40 or more tons capacity, the initial cost of installation is much lower.
12. A larger number of heats can be obtained per week.

Conclusion

A great many boilers already installed could readily be operated economically at a higher rating by merely remodelling their combustion chambers. This is a valuable feature, as many plants do not have room to expand and it would be less expensive than buying new boilers.

The use of pulverized coal is based on sound scientific principles. It permits the utilizing of coal with practically any percentage of ash and the burning out of all the combustible content. Thus it will improve the conditions of burning fuel, extend the life of our fuel deposits, and make useful the vast deposits of low-grade fuels, and burn those of higher grades with the highest possible efficiency.

Fuel Saving in Household Heating

By Robert E. Dillon

Edison Electric Illuminating Company, Boston, Mass.

Home comfort, the household expense account, and the national coal predicament, all demand efficient management of domestic heating plants. It being an acknowledged fact that the average householder burns his coal inefficiently, authoritative instructions as to how to obtain best results from our home plant will be of value to most of our readers.—Editor.

The coal mines of the United States are at the present time producing about 597,500,000 tons of coal per year. It is estimated that about 15 per cent of the total production, or approximately 89,600,000 tons, is used for heating the dwellings of the people.

If by some means the average family could effect a saving of 10 per cent in the consumption of its coal, there would obviously be 8,960,000 tons of coal saved this coming year. At the prevailing price in Massachusetts during the present crisis that would mean a saving of $85,200,000.

From the dollar-and-cent basis it is difficult to analyze the coal question since the monetary figure is distorted by various conditions due to the times, such as the varying value of gold upon which our money is based. From the point of view of the economist, however, there would be released by such a saving the equivalent of 150 3000-ton ships available then for other uses; there would be released an army of 6000 miners who could then be transferred to other industrial or war employment.

This great economy can be accomplished. "Do your bit" has become the motto of the country. If each householder will apply this motto to the manner and way in which he handles his particular furnace, he may accomplish something for himself and for the country. It should not be understood that the object of this article is to advocate less heat in the home. How to obtain the maximum amount of heat from the minimum amount of coal becomes the "burning" question. To accomplish this end, the householder must put some study into the nature and characteristics of fuel and into the characteristics of his heating apparatus.

Some valuable investigations of this subject have been made by colleges and by the United States Government, and it is upon these investigations that the recommendations of this article are based.*

* Technical Paper No. 97, Bureau of Mines, by L. P. Breckenridge and S. B. Flagg.
University of Illinois, Bulletin No. 4, Engineering Experiment Station.
The illustrations in this article are reproduced from these two publications.

Since very little new building is being carried on at the present time, the question of selecting the best type of heater will be passed over, confining the discussion to the operation of heaters already installed, with suggestions regarding the selection of fuel to use in them.

We are accustomed to think only of anthracite or hard coal in connection with the home heater but, if the present war conditions continue over an indefinite period, it may become necessary to make use of other fuels for the purpose. Wood, bituminous coals, peat, coke, fuel oil, gas, electricity—all may come under consideration by virtue of varying price values.

Table I shows the comparative advantages and disadvantages of various fuels for heating, but the value of this table has been somewhat affected by conditions prevailing since it was compiled. As an instance, gas and electricity are sold at the same price as before the war, but bituminous coal has advanced over 100 per cent, and anthracite has advanced over 50 per cent

It should be noted from the table that electricity furnishes the ideal method for heating a house, but on account of the high cost as compared with the price of coal previous to the war, it has been little used for this purpose.

Anthracite coal is the most desirable for household use. The amount of attention required by its use is much less than that by bituminous coal, and for this reason a higher price can be paid for the convenience. Considering the various sizes of coal, there is very little difference in the heating value of one size over another, and if some advantage is offered in price, that size should be used. The method of handling the different sizes, however, is different and requires judicious operation.

Bituminous or soft coal is not as desirable as anthracite for domestic purposes. Before the war the public was willing to pay 50 to 100 per cent more for hard coal than for soft on account of the convenience in handling; therefore, with both coals at approximately the same price it is not probable that the public will resort to soft coal unless the hard coal supply is cut off. If it does become necessary to use soft coal, it will be found advantageous to use sized or screened bituminous coal for the convenience in burning.

But, there is another factor to consider in buying soft coal. The different grades of coal vary in heating value to a considerable

TABLE 1

ADVANTAGES AND DISADVANTAGES OF VARIOUS FUELS AND OF ELECTRICITY

Fuel	Advantages	Disadvantages
Wood	(a) cleanliness, (b) cheerful fire, (c) quick increase of heat, (d) cheap in some localities.	(a) low fuel value, (b) large storage space necessary, (c) labor in preparation, (d) scarcity, (e) does not hold fire long, (f) unsteady heat.
Anthracite	(a) cleanliness, (b) easy control of fire, (c) easier to realize heat in coal than is the case with other coals, (d) steady heat.	(a) price high, (b) difficulty of obtaining, (c) slower response to change of drafts.
Bituminous Coal	(a) low price, (b) availability (c) high heat value (in the best grades), (d) low percentage of inert matters (in the best grades).	(a) dirty, (b) smoke produced, (c) more attention to fire and furnace necessary than with anthracite.
Sub-Bituminous Coal and Lignite	(a) relatively low price (b) availability (in some regions), (c) responds quickly to opening of drafts.	(a) slakes and deteriorates on exposure to air, (b) takes fire spontaneously in piles, (c) heat values generally low, (d) heat in fuel difficult to realize, (e) fires do not keep well, (f) gases generated over fire box sometimes burn in smoke pipe causing excessive heating.
Peat	(a) in general the same as wood.	(a) low heat value, (b) bulkiness.
Coke	(a) cleanliness, (b) responds quickly to opening of drafts, (c) fairly high heat value.	(a) bulkiness, (b) liability of fire going out if not properly handled, (c) fire requires rather frequent attention unless fire box is deep.
Oil	(a) high heat value, (b) immediate increase of heat, (c) cleanliness, (d) small storage space necessary.	(a) high price, (b) difficulty of safe storage.
Gas	(a) ease of control, (b) cleanliness, (c) convenience, (d) immediate increase of heat.	(a) high price in many places.
Electricity	(a) every advantage.	(a) high price.

extent, a factor not present in considering the size of hard coal.

The cost of wood as compared with coal must be small before its use would become an economy, since the heat available from one pound of wood is small.

Sub-bituminous coals, lignite, and peat are very little used in this country. The cost of preparing these fuels is high; but with the mounting cost of transportation there is a possibility that they may soon find a market in localities not far from those where they are produced.

Coke is considerably used at the present time for house heating. It is a by-product of the gas industry, and the demand for it has increased more than the increased use of gas. For this reason coke has increased in price at about the same rate as coal.

Fuel oil and coal gas have been very little used for domestic heating purposes and, even considering the increased cost of coal, it is doubtful whether it would be advantageous to install new apparatus for their use. In addition there would be no real economic saving to the country in the use of gas since it is a product of coal. However, the use of electricity, wood, kerosene, or coal gas for auxiliary heating, such as for individual rooms, fireplaces, bathrooms, etc., would be an economic saving under some conditions.

It is within our power to select the fuel we wish to use, but it must be selected for use in heaters now installed. The common types of heaters in prevalent use are the hot-air furnace, steam-heater, and hot-water heater.

The hot-air furnace costs less to install than any other heater, but its life is less than one-half that of the others. This heater conveys hot air to the rooms of a house by virtue of the fact that hot air is lighter than the cold outside air and rises. Air, therefore, must be freely supplied from the outside. Moisture must be supplied to the heated air since health requires it. Heated air has a greater capacity for holding moisture than has cold air; and unless moisture is supplied the hot air will absorb moisture from the skin and, since the process of evaporation cools the body, more heat will be required to produce the same sensation of warmth. Furthermore, furniture and woodwork will soon go to pieces if there is insufficient moisture..

The water-pan in a furnace is too often

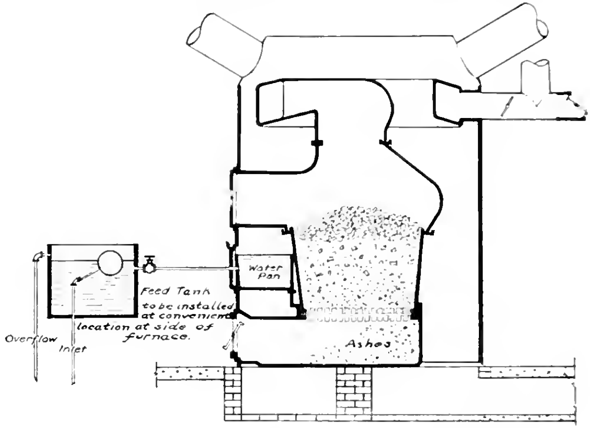

Fig. 1. Diagram showing Convenient Method of Keeping Water-pan Filled, also Conditon of Ashes which Should Not Exist

neglected. A convenient method of keeping this full is shown in Fig. 1.

The first cost of a steam or a hot-water system is much greater than that of a hot-air system. A hot-water system is more expensive than a steam system to install, but with regard to their relative economy, the reverse is true. Relatively the hot-water system is the most economical, the steam system the next, and the hot-air the poorest.

The reason that the hot-water system is more economical comes from the fact that water will circulate under wide variations in temperature. Heated air, on the other hand, must be hot in order to rise. Steam has a constant temperature at about 212 deg. F. for low pressure. For these reasons, hot water will give a heat more uniform than that supplied by the other systems.

If the heating system provides for ventilation from the outside, more coal must be used. This is true, not only for the furnace which draws air from the outside, but for the other systems where the air is changed in the rooms. The extra amount of coal required for this ventilation will depend upon the number of times per hour the air of the rooms is changed. Even at an additional expense it is advisable.

from the stand-point of health, to have some means of ventilation.

With any fuel and any system of heating, the most important factor in economy is the method and care taken in operation. The one who pays the fuel bills will undoubtedly

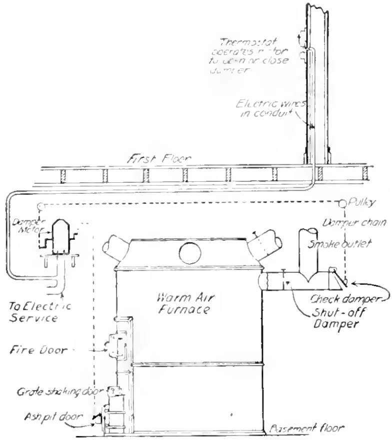

Fig. 2. An Ingenious Electrical Device for Maintaining an Even Temperature in the House

exercise the greatest care, so that naturally the man who attends his own heater obtains the best economy if his methods are correct.

Even regulation of heat is one of the principal methods of saving coal. Anticipate the cold periods of the day and open the drafts soon enough to gradually increase the heat, and check the draft before the house becomes overheated.

For complete control of the draft, the heater should be equipped with a damper to the ash pit, a check damper and a shut-off damper in the smoke-pipe. The damper to the ash pit allows air to reach the fire. The check damper allows the draft created in the chimney to draw air from the cellar instead of through the fire. The shut-off damper allows the fire to be shut off from the chimney. This damper should be arranged so that it is impossible to completely shut the fire box from the chimney, since otherwise explosions of coal gas may occur. When soft coal is burned, a lift damper on the fire door is also necessary to relieve gas explosions.

The door over the fire should never be opened for cutting down the heat unless the house becomes uncomfortable. Opening this door reduces the heat delivered for the coal burned. The check damper should be opened instead.

If the heater does not burn enough coal to produce the necessary heat for the house when all drafts are open and check draft closed, an inspection should be made of all flue passages, the stack, and the chimney to see that they are clean and connections tight. The chimney should extend above all near-by obstructions. The area of a cross-section of the chimney should be at least one-eighth of the grate area. If these conditions are fulfilled the heater should supply enough heat unless it is too small for the work it has to do.

An ingenious device for maintaining an even temperature within the house is shown in Fig. 2. It consists of a thermostat and an electric motor for controlling the dampers so that very little personal attention is required.

Another essential feature in operating the heater for maximum efficiency is a method of uniformity in firing. If the heater is large enough, put the full supply of coal for 24 hours on at the banking period at night. This will cool the heater for the night and will allow a gradual ignition. If firing is required more than once a day, coal should be put on in the morning after the house is warm, but the quantity fired at this time should be as small as possible. The heavy firing should be done at night.

When firing is necessary in the daytime, the live coals should be pushed back and the fresh supply filled in to an even height in front. In this manner the live coals at

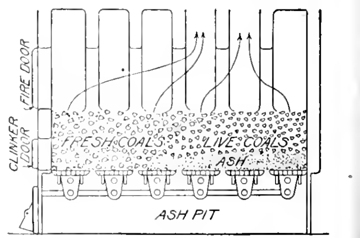

Fig. 3. Method of Firing Coal to Burn All Coal Gas

the back will ignite the gases from the freshly fired coal and in addition the house will not cool off to so great a degree. Firing in this manner is absolutely necessary in soft-coal burning. Fig. 3 shows how this method is carried out.

If holes burn through the fire, cold air is admitted to the fire box. To prevent this a heavy fire should be kept.

If the heater has proved too small, its capacity for heating may be increased by using a large-size coal. This allows a greater draft through the fire, causes a greater amount of coal to be burned, and more heat to be produced.

The grates should never be shaken at night. This should be done in the morning when the heat is required. It should be done with care, stopping when a small amount of light can be seen from the fuel bed. In mild weather, by allowing a layer of ashes to remain on the grate, the draft may be cut down and the heat kept low. Following these methods of shaking will cut down the loss of coal to the ash pit, and eliminate the disagreeable job of sifting ashes.

Ashes should never be allowed to accumulate under the grates, as they reflect the heat and tend to warp and burn the grates.

Of equal importance to the losses in the chimney and ash-pit are those due to radiation, and another loss which occurs from the decreasing capacity for heat absorption by the heater.

The radiation loss is often as high as fifteen per cent. This figure can be cut to five or ten per cent by coveiing the pipes and conserving the heat for the rooms rather than for the cellar.

The loss due to the decreasing capacity for heat absorption by the heater is frequently large and receives little attention. Such heat as is not readily taken up by the heater passes on to the chimney. This heat may be turned into useful heat if the hot smoke flues are clean and all heat transferring surfaces free from soot. Soot is an almost perfect heat insulator, and a layer upon the heating surfaces will cut down heat delivered to the heating medium to a very large extent.

The foregoing recommendations pertain principally to the use of hard coal. Hard coal will undoubtedly remain the predominating fuel for household uses in this locality for some time to come.

It is not so much a question of shortage of coal as it is lack of transportation facilities, and one coal is as readily transported as another.

However, if the situation changes and soft coal comes into use, the householder will find it necessary to use new methods in handling his fire. Frequent firing becomes necessary. Means must be adopted to reduce the excess smoke and to consume the volatile gases. For this purpose air must be admitted over the fire after a fresh coaling so as to mix freely with the gases and burn them.

Coke requires about the same methods for burning as does hard coal, but with additional attention. It burns freely and burns out quickly. It should be well ignited before the drafts are closed, for otherwise it will go out.

Wood is very free burning and difficult to control. It also offers no chance for banking.

In conclusion, it may be noted that a considerable saving may be effected in the use of coal by a methodical procedure and a careful watchfulness for deteriorating influences. This may be summed up in a few suggestions. See that the firing is done at as infrequent periods as possible; that the grates are not shaken too often; that the temperature is kept uniform; that the radiation is small; and that the heating surfaces are clean.

PREVIOUS INSTALMENTS OF THE SERIES

An Improved System for Lighting Interurban Trolley Cars

By W. J. Walker

Supply Department, General Electric Company

We are all familiar with the annoying variation in lighting on our interurban trolley cars, ranging all the way from blinding brilliance to practically no illumination at all as the result of variations in trolley voltage. This condition is not only objectionable to the passengers, but where headlights are operated from the trolley a very serious element of danger is introduced, owing to the inability of the motorman to see along the right-of-way, and to the absence of the warning beam of light to automobile drivers and pedestrians at road crossings. This condition has been overcome by the development of a motor-generator set, the generator of which is designed to maintain practically constant voltage over a wide range of speed. On the usual 600-volt system this motor-generator will maintain satisfactory illumination over a voltage range of 600 to 200 volts.—Editor.

The public, educated to a higher lighting standard through use of Mazda lamps in the home, is demanding an improvement in the lighting of trolley cars. These demands are in some cases being enforced by public service commissions. Furthermore, good lighting is desirable on grounds other than that of public convenience—it is good business. Leading authorities have proved conclusively that better lighting may be had in the average car with an increase in operating economy. In fact, experience has shown that the installation of the modern reflector method of lighting, using Mazda lamps and reflectors, with the units arranged in a single row in the middle of the center deck, has paid from 10 per cent to 35 per cent interest on the investment. It is, therefore, not surprising that the system is being extensively employed in new cars and that many roads are changing over existing equipments.

This improvement, however, leaves something still to be desired, especially on the interurban properties where the voltage variation inherent in all trolley systems is at its worst. Good lighting here under full voltage conditions serves mainly to emphasize its absence under the voltage conditions usually obtaining.

With the increasing highway traffic and the necessity forced upon the high speed interurban railways of preventing night crossing accidents, the headlight problem, too, becomes a matter of the gravest concern with varying voltage. This is not a problem of convenience—safety itself is involved, and good headlighting must be had at any cost.

The incandescent headlight equipped with parabolic reflectors, accurate focusing devices, and the concentrated filament Mazda C lamp would easily meet most service requirements were it not for the trolley voltage variation, to which this lamp is even more susceptible than the luminous arc now generally used. It has not been largely adopted in high-speed service principally because there are few railways having a sufficiently constant voltage to permit its use.

Obviously, the need of the interurban railways is some device for controlling the voltage of the lighting circuits. Several such devices are now offered, but few, if any, of them meet all the requirements of interurban service.

New Constant Potential Generator

The General Electric Company has developed and recently placed on the market a motor-generator set that is peculiarly suited to railway car lighting, in that the generator, which is of a new design, provides a practically constant voltage over wide variations in speed.*

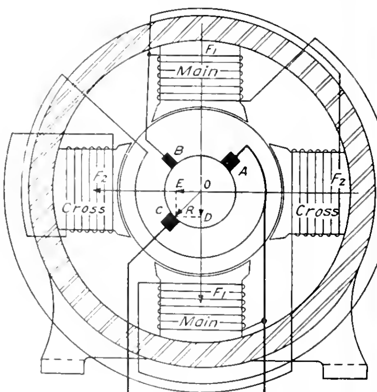

Fig. 1. Diagrammatic Sketch of Constant Potential Generator

* A fuller explanation of the principles of this generator will appear in an early issue of the Transactions of A. I. E. E., in an article by Mr. S. R. Bergman.

Fig. 1 illustrates diagrammatically the principle of the machine. The armature is series wound and the field contains twice as many poles as the number of poles for which the armature is wound. In the case illustrated the armature is wound for two poles and the field contains four poles symmetrically located. The load is taken from the brushes A and C, and in addition to these load brushes there is a third brush B placed 90 electrical degrees from the load brushes. The field may be considered to consist of two independent magnetic circuits. One of these, $F\text{-}1$, is saturated and the corresponding flux, $f\text{-}1$, may be called the main flux of the machine. The second magnetic circuit, $F\text{-}2$, is not saturated and the corresponding flux, $f\text{-}2$, will be called the cross flux. The main flux generates, between the brushes A and B, an electromotive force called the main voltage of the machine, but it does not generate any e.m.f. between the brushes B and C. Similarly, the cross flux generates, between the brushes B and C, an e.m.f. which will be called the cross voltage, but it does not generate any e.m.f. between the brushes A and B. The excitation which is taken from brushes A and B consists of two multiple branches, one branch exciting the main poles and the other branch exciting the cross poles.

The direction of the main and cross fluxes is such that the difference between these fluxes is interlinked with the line brushes A and C, as shown in the figure, and thus the line voltage AC is the difference between the main voltage AB and the cross voltage BC, i.e., the voltage AC is equal AB minus BC. Since the main circuit is saturated the main flux remains constant and the main voltage AB is proportional to the speed. Therefore the excitation of both the main and the cross fields is proportional to the speed. As the cross circuit is not saturated the cross flux will increase in proportion to the speed, and hence the cross voltage BC must increase with the square of the speed. As the speed increases AB increases, but since BC increases faster the difference is constant, and test shows that $AC(=AB-BC)$ can be made constant over a wide speed range. In order to get best results the cross magnetic circuit should not be reduced too far below saturation, since then the cross voltage builds up too fast, but it should first be unsaturated and finally made to approach saturation.

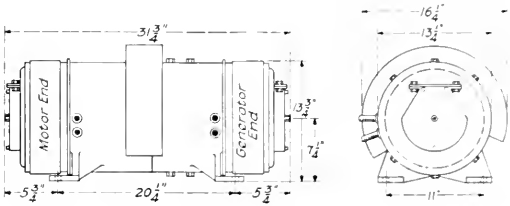

Fig. 3. Outline of Motor-generator Set

Since the line current is taken from the brushes A and C (Fig. 1), there exists an armature reaction OR in the direction AC. This armature reaction may be resolved into two components, one OD in the direction of the main flux and the other OE in the direction of the cross flux. As the main magnetic circuit is saturated, the additional excitation, due to the armature reaction, cannot add anything to the main flux. The component OE will, however, interfere with the cross flux and disturb the regulation of the machine if not counteracted. In order to overcome this influence a series winding is added to the cross poles. This winding has an equal and opposite strength to the armature reaction working in this direction, and will be called the compensating winding. The location of this winding is shown in Fig. 1. It will be easily seen that by changing the strength of the compensating winding it is possible to obtain either rising or falling line voltage with increasing load. By over-compensation the voltage will rise with the load and with under-compensation it will fall. Obviously the strength of the compensating winding can be made to just balance the IR

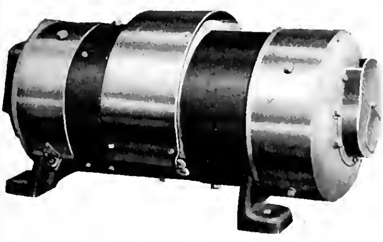

Fig. 2. Motor-generator Set for Interurban Car Lighting

TABLE I

	HEADLIGHT		INTERIOR CAR LIGHTING	
	Series Equipment	Low Voltage Installation	Series Equipment	Low Voltage Installation
Method of Lighting	Luminous arc 4.0 amps. at 600 volts	Form J-28 incandescent with 250-watt, 32-volt, Mazda C lamp	7 series circuits of 5–23-watt, 120-volt Mazda lamps along half decks. No reflector	1 multiple circuit of 8–75-watt and 4–25-watt, 32-volt Mazda "B" lamps along center deck with wide angle opal reflector (See Fig. 2)
Source of Energy	1200–600 volt dynamotor	1.5-kw., 650–32-volt constant potential motor generator set operated from 1200–600-volt dynamotor	1200–600 volt dynamotor	1.5-kw., 650–32-volt constant potential motor generator set operated from 1200–600-volt dynamotor
Power Consumption	2400 watts	*500 watts	805 watts	*1400 watts
	Maximum distance at which it was possible to distinguish a man in dark clothing standing at center of track			
Performance	Varied from 300 to 1500 feet	1300 feet at poorest voltage condition	Varied from dazzling brilliancy to inability to read	Not possible to detect any change in car illumination during test

* Including losses in conversion.

TABLE II

	HEADLIGHT		INTERIOR CAR LIGHTING	
	Series Equipment	Low Voltage Installation	Series Equipment	Low Voltage Installation
Method of Lighting	Carbon arc 4.5 amps. at 600 volts	Form J-28 incandescent with 250-watt, 32-volt Mazda C lamp	3 series circuits of 6–56-watt, 110-volt Mazda lamps along half decks. No reflector used	1 multiple circuit of 7–75-watt, and 3–25-watt, 32-volt Mazda "B" lamps along center deck with Alba No. 4129 reflector (See Fig. 2A)
Source of Energy	Third rail	1.5 kw., 650–32-volt constant potential motor generator set operated from third rail	Third rail	1.5 kw., 650–32-volt constant potential motor generator set operated from third rail
Power Consumption	2700 watts	*500 watts	1008 watts	*1200 watts
	Maximum distance at which it was possible to distinguish a man in dark clothing standing at center of track			
Performance	With third rail voltage varying between 350 and 625 volts 300 to 1000 feet. At minimum of 150 volts arc extinguished	With third rail voltage varying between 350 and 625 volts 1300 feet. At minimum of 150 volts, 700 feet	Glaring brilliancy at 625 volts to inability to read at 350 volts and 150 volts practically dark	From 625 to 350 volts no noticeable variation. Possible to read as low as 200 volts.

*Including losses in conversion.

drop in the machine, resulting in a flat compounded generator.

Application to Trolley Car Lighting

The new system is operated at a potential of 32 volts. The selection of this voltage was influenced by several important factors, namely, minimum weight and size of machine; the need of low voltage energy for the operation of incandescent headlights; multiple operation of lamps, eliminating circuit outages and permitting the use of larger units with consequent reduction in lamp maintenance; the use of a lamp standardized for steam roads; and lastly, provision of a source of low voltage energy in high voltage installations for the operation of Type PC control equipments.

The system is in operation on interurban electric railways, operating under widely varying service conditions, and is giving entirely satisfactory results.

On a typical installation, heavy freight and passenger trains are operated from a 1200-volt trolley, and as a result of the heavy traffic the trolley voltage varies between wide limits and gives very unsatisfactory lighting results. Frequent grade crossings complicate the headlight problem.

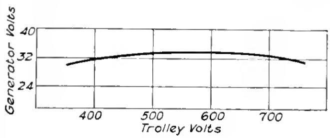

Fig. 4. Generator Voltage with Variation in Trolley Voltage

A comparison of the equipments installed on this system, with a tabulation of the results obtained from each, is given in Table I. Attention is called to the wide voltage variations of the series equipment and the variation in the headlight and interior lighting. With the low voltage equipment, under precisely the same conditions, no change in the interior lighting is noticeable, and the headlighting under the poorest voltage condition compares very favorably with that of the series system at its best.

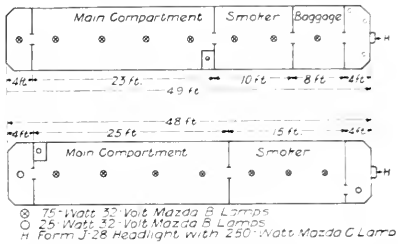

Fig. 5. Installation of Lighting Units on Interurban Cars

On a typical third rail installation very dense traffic movements cause wide voltage variations, with inadequate car illumination and poor headlight protection. The 3rd rail gaps are a further source of annoyance, causing repeated blinking of the interior lights and interference with the headlight.

The results obtained under these conditions are shown in Table II. Here the voltage ranges from 625 to 150 volts, or from glaring brilliancy to near-darkness with the series equipment, while the motor-generator set is maintaining practically constant interior illumination down to 350 volts and a readable

TABLE III

*ANNUAL LIGHTING COST

	Series Equipment	Low Voltage Equipment
Approximate annual power cost per car at $.0175 per kw-hr. Headlight and interior lights burning† 1707 hours per year. Haulage estimated at $.05 per lb. per year	$104.54	$85.51
Estimated annual depreciation (including interest on investment) per car	11.00	33.00
Estimated annual maintenance per car	77.50	35.00
Total annual cost per car	$193.04	$153.51
Annual saving per car		$39.53

*Based on equipments listed in Table II.
†Report of Equipment Committee A.E.R.A., 1914.

Fig. 6. Trolley Potential, 200 Volts

Fig. 7. Trolley Potential, 250 Volts

Fig. 8. Trolley Potential, 350 Volts

Fig. 9. Trolley Potential, 600 Volts

Photographs showing Maintenance of Satisfactory Lighting by Motor-generator Set, with Variation in Trolley Potential from 200 to 600 Volts

interior as low as 200 volts. At 150 volts the headlight is projecting 700 feet, and from 350 to 650 volts a distance of 1300 feet; whereas, with the ordinary series system the light is out at 150 volts and the projection between 350 and 650 volts varies from 300 to 1000 feet. In other words, the low voltage equipment is furnishing at 350 volts trolley as good interior illumination and a considerably better headlight than the series system furnishes at any voltage.

On the latter installation photographs of the interior illumination were taken at varying voltages, care being taken to have the same lens aperture opening, length of plate exposure, and plate speed in each case. In order that the comparison might be accurate extreme care has been taken to have the half-tone engravings represent faithfully the exposed plate.

The illumination at 350 and 600 volts trolley is shown in Figs. 8 and 9, and that at 200 volts in Fig. 6. Figs. 7 and 11 show the comparative effects at 250 volts trolley of center and half deck lighting, the former by means of the motor-generator set and the latter by current supplied directly from the third rail.

Tests were made to determine the drop in generator voltage corresponding to the time in seconds required to span the third rail gaps. The results at 500 volts trolley are plotted in Fig. 10. With the low voltage system, the third rail gaps will not seriously interfere with the car illumination and constant headlighting is assured.

When it is considered that these results are obtained with actual savings in power and maintenance, as shown by Table III, the showing is the more remarkable. The operating figures will vary with the cost of power, up-keep, etc., but those given are considered

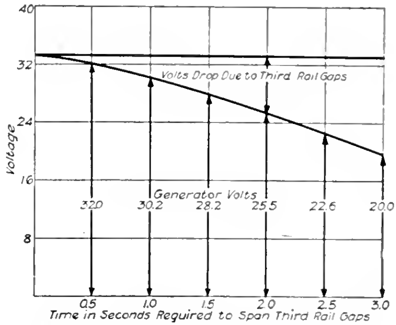

Fig. 10. Drop in Generator Voltage While Crossing Third Rail Gaps

conservative and in accord with the conditions existing on the average system.

It has been demonstrated that exceptional car lighting, both headlight and interior, may be had at a lower cost than now prevails, and under these conditions the new system should find extensive application in the lighting of new cars and the changing over of existing unsatisfactory equipments.

Fig. 11. Series Lighting, 250 Volts, Half-deck Arrangement of Lighting Units (Compare with Fig. 8)

Some Experiments in the Use of Electric Power for Field Work on the Farm

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and

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This article considers the possibilities of electric power for cultivating farm lands where power may be obtained from existing transmission lines. It does not comtemplate the isolated generation of power nor the use of storage batteries. The tests were performed with a tractor built largely from parts of other machines, and hence does not show the efficiency that could be expected from a standardized machine. This experimental machine demonstrates, however, that it is perfectly practical to cultivate soil by the proposed method; that the overload capacity of the electric motor is an important factor in this work; and that the power consumption is such as to effect a considerable saving for each cultivation over the use of horses, as well as a saving in laborers' time. It is almost certain that powerful tractors, either electric or gas-engine driven, will before long replace the horse in the cultivation of the soil; and where electric power is at all available the electric motor-operated tractor will prove to have decided advantages in its simplicity and lower operating costs.—Editor.

With the rapid increase in the number of internal combustion motors and the pending scarcity of the more volatile petroleum fuel products, it is well that consideration be given to other sources of power. Hydro-electric power should at least receive careful consideration for all purposes where it can be used.

The advantages of electric power for field work, where the load must necessarily be irregular, are quite obvious. The simplicity and reliability of the electric motor is not exceeded by any other motor; much of the engineering is confined to the power house, and the ability of the electric motor to carry temporarily a heavy overload gives it a decided advantage for agricultural work where the load is constantly varying. The large starting torque, light weight, and compactness are likewise of importance in this service.

In California the use of electric power on farms for pumping, lighting, and general power purposes is now extensive. A survey made in 1915 by a committee of a Western power association indicated that the total horse power in electric motors on the farms was in excess of 190,111, and by this time (January 1918) the total is 200,000 horse power. The total number of consumers is about 14,000. It is significant that this electric power exceeds the electric power used on all the rest of the farms in the United States.

At the present time water power in California has been developed to the extent of 600,000 horse power, although fuel oil has been very cheap in recent years. It is stated upon good authority that the total available water power in the state is 6,000,000. It would, therefore, seem reasonable to expect an extension of the use of electric power on the farm in the future.

It is on farms where intensive agriculture is practiced and where electric power is now used for pumping, *where the transmission lines are installed*, that the field of electric power will be extended. Most of these farms are either truck farms or farms producing crops of high value per acre. Although California is a state of large ranches, there are, according to the 1910 census, 43,139 farms of less than 50 acres, and 22,525 less than 20 acres. Incidentally this land, as shown by the census, has an average value of $500 per acre. Thus it is seen that the farms of California could use a large amount of electric power without involving any serious transmission problems, and if its use were made possible it would not only replace much of the power now being used, but also reduce the amount of hand labor necessary.

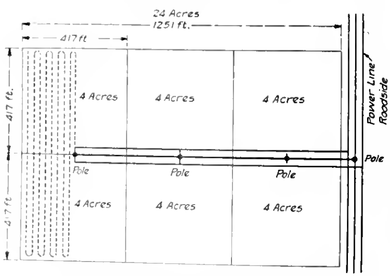


Fig. 1. Diagram showing Arrangement of Power Feeders and Method of Cultivating 24-acre Plot

In order to secure some definite data concerning the possibilities of electric power for field work the authors conducted an experiment which involved the following distinct features:

Design and construction of an experimental electric tractor.
Practical field test of tractor.
Tests to determine power consumption.
Analysis of results and conclusions.

The experiment was confined to the use of power obtained direct from a commercial transmission line, and storage batteries were not considered.

The tractor was designed for truck crop work. Two drivers were used with a cultivator as an integral part. It was designed to travel 140 feet per minute and was driven by a 3-h.p., 220-volt, 3-phase motor. The machine was made by utilizing parts of other machines as far as possible. The drivers were 32 in. in diameter, with a 4-in. face. Three speed reductions were required, which were effected by a belt, a bevel gear set, and a spur gear set. The machine carried a cable reel, and through the operation of a friction clutch the cable could be played out or wound up as desired. In operation the cable was dropped at the side of the tractor when traveling away from the main power line and picked up on the return. It was necessary to shift the cable connection at the end of the field occasionally by moving the plug connector to a new receptacle. The experimental machine, complete with 180 feet of cable and cultivating attachments, weighs 735 lbs.

The methods of cultivating the soil and distributing the electric power are illustrated in Fig. 1.

Conservative estimates made in collaboration with the power company engineers indicate that the poles and line material necessary for the installation outlined in Fig. 1, even at the present high prices, will not exceed $110. The estimated price of the machine is $500; thus, for $610 the equipment could be put on a farm ready to operate. These figures make liberal allowances for manufacturing and merchandising, and for the electrical man on the installation.

Although it is a fact that the equipment has limits on its radius of operation as compared with a horse (which, together with harness,

Figs. 2 and 3. Front and Rear Views of Electric Tractor, showing Cable Reel, Control Levers, etc.

would cost in the average of $275), it should not be overlooked that the machine is capable of doing many things that a horse cannot do. For instance, it constitutes a portable motor which can readily and easily be moved about the farm by one person to be belted to a wood-saw, churn, pump, feed grinder, cider mill, grindstone, spraying machine, etc.

An important feature of an equipment of this character is the fact that it is capable of working continuously, where a horse can work only intermittently.

After construction, the experimental tractor was given a field trial. No difficulty was experienced in handling the machine, although it was not to be expected that the first machine would be free from many impractical features. However, the machine worked better than the authors anticipated. The cable was easily managed, and the fact that the machine was tethered was not so much of an inconvenience as might be expected. It was unusual to find a machine working so quietly and with so much reserve power. The tractor in hard ground, where the cultivator was set deep, would slip its drivers while the motor developed an overload of 250 per cent.

was 2.9 per cent; also that while reeling the cable the power consumption was less than when playing it out. This was due to the fact that the pull of the cable assisted in moving the tractor, while when unwinding there was a drag due to friction in the reel.

The following conclusions were deduced after the completion of the tests:

a. It was demonstrated by a crude experimental machine that the soil could actually be cultivated by electric power and that at least there were no fundamental obstacles.

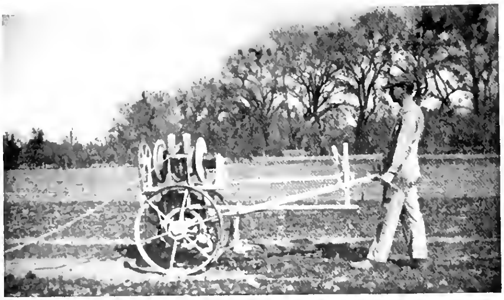


Fig. 4. Tractor in Use

Records were made of current consumption, and the following data were secured:

Normal cultivation, current consumption, 1867 watts.
Deep cultivation, current consumption, 2500 watts.
Drivers slipping, current consumption, 3200 watts.
Recultivation on soft ground, current consumption, 2400 watts.
Cultivator on soft ground, current consumption, 2200 watts.

A draw-bar horse-power test was made by detaching the cultivator and substituting a stone boat for a load.

Draw bar pull, 2285 pounds.
Time required to travel 100 feet, 46.8 seconds.
Draw bar horse power, 0.88.
Input-electrical horse power, 2.94.
Over all efficiency, 29.8 per cent.
Estimated output of motor, 2.18 h.p.
Efficiency of tractor, 35.5 per cent.

The efficiency of the outfit was very low. This can be attributed to the crude gearing used and the excessive friction of the bearings, which were not in the best of condition.

It was noted during the tests that the slippage of the drivers while doing normal work

b. For garden work a light machine is desirable, keeping the power consumption low and making the machine easy to handle.

c. The overload capacity of an electric motor is an important feature in its favor.

An effort has been made to compare the cost of cultivating and plowing by a horse and with this machine. It is very difficult to draw any accurate conclusions because there are so many varying and intangible factors entering into the maintainance of a horse equipment. The following approximations, although not suitable from which to draw any definite conclusions may, nevertheless, be of some general interest.

First. Due to the greater rate at which work can be done and the continuous period over which it can be performed, it is believed that where it would take a horse about 11 hours to cultivate 8 acres (the work, of course, not being done in 11 consecutive hours), the machine could do the same acreage in possibly

8 hours (there being no question about the fact that it could be done in 8 consecutive hours). This means efficiency in the use of labor incident to operation.

Second. Although, as stated above, the cost incident to the maintenance and operation of a horse equipment is very uncertain, estimates indicate that in the cultivation of a 24-acre tract, as illustrated, there would be at least a saving of $7.50 for each cultivation in favor of electricity, plus at least a day and a half in time saved by the person operating the equipment. Opinion differs as to the number of cultivations necessary for different crops, but, of course, the more cultivations the greater the saving.

Third. It is interesting to consider what the use of this outfit will mean to the farmer with property under 40 acres, taking into account the question of how much acreage is necessary to provide pasturage and feed for horses. Any saving in this direction means a transference from the expense account to the income account.

Fourth. Expenditures for feed for the horse should not be overlooked in considering the cost of operation.

In conclusion, it is apparent from the fact that 200,000 h.p. in electric motors is now actually being used on the farm that the phrase "Electricity on the Farm" does not constitute an idle dream any longer. Although 160,000 h.p., of this is used for irrigation and reclamation purposes (a peculiarity to semi-arid sections), the remainder, or 40,000 h.p., is actually being used for miscellaneous farm purposes, such as were enumerated in connection with the varied uses to which the machine in question could be put on the farm. The only thing that we are not doing with electricity on any scale is plowing and cultivating, and this now bids fair to be a commercial reality in the very near future.

Graphical Representation of Resistances and Reactances in Multiple

By H. C. Stanley

San Francisco Office, General Electric Company

Frequently a number of resistances or reactances are connected in multiple and it is desired to know their total or combined value of resistance or reactance. The calculation necessary to obtain this combined value is usually simple in principle but at times laborious in practice. For approximate results and as a check on the more accurate calculations, a graphical solution is sometimes of value. The present article outlines briefly the graphical solution of some representative cases.—Editor.

The graphical representation of resistances in series is very simple, consisting merely in laying them out in a straight line, the total length of the line representing the total resistance. This procedure is shown in Fig. 1, where a, b, c and d represent the individual resistances and e the total resistance.

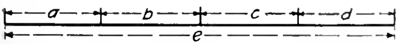


Fig. 1

When resistances are in multiple the graphical representation is more difficult. A method, however, is as follows:

Let a and b, Fig. 2, represent any two resistances which are in multiple. As is well known, the total resistance is the reciprocal of the sum of the reciprocals of the individual resistances. The lengths a and b are erected perpendicularly to a base line at any convenient distance apart. Diagonals are then drawn as shown, and the perpendicular r from the base line to the intersection of the diagonals represents the value of a and b in multiple. This is proved as follows:

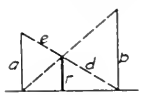


Fig. 2

Let d and e be portions of one of the diagonals as shown in Fig. 2.

Then $\frac{a}{b}=\frac{e}{d}$ (being corresponding sides of similar triangles) and $\frac{r}{a}=\frac{d}{d+e}$ (being corresponding sides of similar triangles).

Then $r=\frac{ad}{d+e}=\frac{a}{1+\frac{e}{d}}$

Substituting $\frac{a}{b}$ for $\frac{e}{d}$ we have

$$r=\frac{a}{1+\frac{a}{b}}=\frac{1}{\frac{1}{a}+\frac{1}{b}}$$

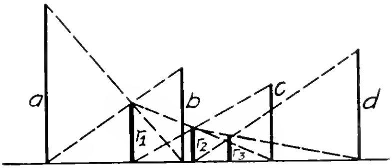


Fig. 3

The last expression is the reciprocal of the sum of the reciprocals of the individual resistances.

Fig. 3 shows four resistances a, b, c and d in multiple. This is merely a continuation of Fig. 2. Sections a and b in multiple give r_1, r_1 and c in multiple give r_2, and r_2 and d in multiple give the final value of r_3.

One convenience of this graphical representation might be suggested as follows:

Suppose that we desired to investigate the value of a number of resistances in multiple, assuming all units of resistance to be equal, by laying the resistances off at equal intervals, a curve can readily be drawn which shows that after a certain point very little can be gained by the addition of a single unit. This is shown in Fig. 4.

A series-multiple combination of resistances is shown in Fig. 5 wherein a, b and c represent respectively the resistances of the three legs of a delta-connected circuit. The

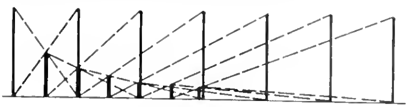


Fig. 5

lines x, y and z then represent the resistances between the corners of the delta. This diagram shows a and b in series, and in multiple with c, whereby the value of y is obtained, the values of z and x being arrived at similarly.

The preceding formulæ and diagrams will of course apply equally well to reactances operating in series or multiple.

Now let us consider the case of resistances and reactances when used together. In Fig. 6, let r represent the resistance and x the reactance, being drawn at right angles to each other.

If the resistance and reactance are in series, then the hypotenuse represents the impedance. If, however, the resistance and reactance are in multiple, the impedance is

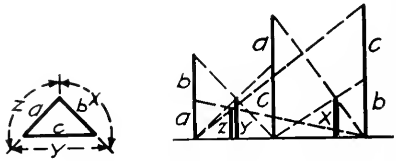


Fig. 4

represented by z, z being the perpendicular drawn from the hypotenuse to the opposite angle. The proof is as follows:

$$Sin\ \phi=\frac{x}{\sqrt{x^2+r^2}}$$

Also

$$Sin\ \phi=\frac{z}{r}\text{ or } z=r\ sin\ \phi.$$

Then $z=\frac{r\,x}{\sqrt{r^2+x^2}}$, and dividing by $r\,x$ we have

$$z=\frac{1}{\sqrt{\frac{1}{r^2}+\frac{1}{x^2}}}$$

This is the established equation for resistance and reactance in multiple.

If there are several reactances and resistances in multiple they should first be taken separately as in Fig. 3, and then the resultants combined as in Fig. 6.

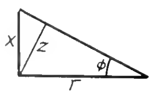


Fig. 6

If the principle shown in Fig. 6 is used on an ordinary piece of co-ordinate paper, this provides a simple and ready means for determining what multiple combinations of resistance and reactance are necessary in order to obtain any required values of impedance. In fact, it might be stated that investigation on any of the lines proposed in this article can best be carried out on co-ordinate paper.

Electric Cargo Winches

By E. F. Whitney

Portland Office, General Electric Company

The use of electricity on shipboard is increasing rapidly in both the variety and the extent of its applications. Most ships today are electrically lighted, have their fans, pumps, etc., electrically driven, and are equipped with a radio outfit. In addition to these applications, the galleys of many ships are electrically equipped, and a considerable number of ships are electrically propelled. A comparatively recent but equally successful development is the application of electric drive to cargo winches: and the following article treats of this subject. The magnitude and characteristics of winch work are defined, the electrical equipment is described, and the superiority of its operation over steam-winch operation is discussed in terms of reliability, speed, control, cost, and efficiency.—Editor.

The application of electric motors to hoisting and conveying equipment has been successfully carried out in practically all classes of work requiring such equipment, so that today the electric drive is universally accepted as being the most efficient, reliable, and expeditious.

With the recent activity in the shipbuilding industry of this country and the imperative demand for propelling equipments, the geared turbine sprang into favor overnight and became a newly accepted standard for American shipbuilders. Because of its merit it at once established itself in an unassailable position.

Another idea having to do with the positive, efficient, and speedier handling of cargo was also presented to the shipbuilders. This was electric drive for cargo winches, which tradition and precedent had determined should be operated by steam. The unprecedented activity in auxiliary motor ships (which combine the use of sails and oil engines for propulsion) has given the electric winch its opportunity, and the results indicate a marked improvement over steam-winch operation.

During the past few years much attention has been given to terminal freight handling, but very little has been given to a careful analysis of the handling and loading methods employed by the carriers themselves. It is evident that each exerts its influence on the other and that the greatest benefits can be obtained only when a close balance is struck between dock facilities for handling and carrier facilities for loading and unloading.

In this article those vessels will be considered which must be equipped to handle all of their cargo through deck hatches, and which cannot, because of the varied character of the ports of call, count on dock facilities for help. This class of vessel embraces by far the largest part of our ordinary commercial carriers.

The duty of cargo winches may be divided into two general classifications:

(1) High rope speed (handling moderate unit weights of cargo).
(2) Moderate rope speed (handling heavy unit weights of cargo).

The first class involves the handling of miscellaneous cargo loads where the greater part of the cargo is made up of relatively small packages and is handled in slings.

The second class applies to specialized cargo. The line of division is not definite and it will usually be found that the same equipment is expected to perform both classes of service, so that a compromise is necessary. The range of duties specified is found to be from 1500-lb. sling loads at 250 feet per minute to 12,000-lb. sling loads at 75 feet per minute. For average heavy work loads range from 3000 pounds to 5000 pounds at 175 feet to 125 feet per minute, and for light work

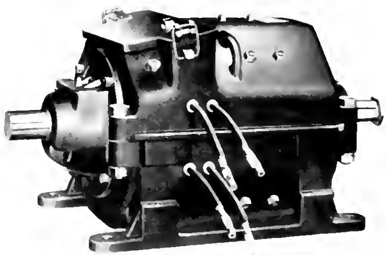


Fig. 1. Winch Motor, Side View, Totally Enclosed

from 700 pounds to 3000 pounds at 250 feet to 175 feet per minute.

The limiting factor in the speed of loading a vessel should be the capability of the men in the hold to stow away the cargo. With slow speeds and light loads the cargo can be stowed faster than it can be handled by the winches; so that the present tendency is to increase the load and the speed of the winches (that there may always be work ahead for the men in the hold), and to increase the number of men to the maximum at which they can work effectively. This requirement necessitates a very flexible hoisting drive, one capable of operating at high speeds with light loads and at moderate speeds with heavy loads —in every case maintaining the highest average speed compatible with safety in handling the cargo. For this purpose, the series direct-current motor is admirably suited, and when adapted to a given winch design will give higher average speeds throughout the range from light to heavy loads than can be obtained by other methods. This is one of the features making for dispatch in loading.

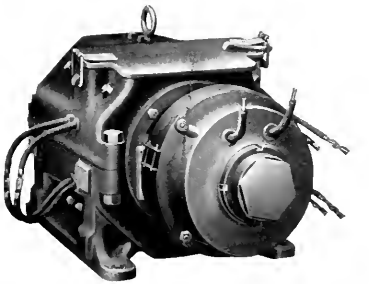


Fig. 2. End View, Winch Motor, showing Weatherproof Brake Mounted on Shaft

Today, with charters soaring and vessels in demand as never before in the history of the world, each day lost in loading or unloading cargo at the dock is so much unproductive time that can never be regained. Speed in handling cargo is therefore of extreme importance. Each day saved means that the vessel has not only saved a day on its voyage and has released terminal space for other cargo, but also that the owners have saved an extra day for the entire force of stevedores and longshoremen required to handle cargo, and that these men are released for duty on some other vessel which in its turn will get away on its voyage that much sooner. Therefore, in choosing winch equipment the items to be considered are:

(1) Reliability,
(2) Speed of handling,
(3) Cost and efficiency of operation.

Reliability

Unless the equipment will be ready to operate when required, it cannot be considered. This presupposes a certain degree of simplicity and demands rugged equipment which will require very little adjustment and be easy to repair. Untried or experimental machinery as well as new designs of equipment cannot be considered (unless, of course, an experimental or trial installation is being made).

The types of motors and controls recommended are of standard designs which have been used for a number of years. The motors are enclosed and are weatherproof, with shaft packing to protect the bearings from water. They are geared direct to the winches and are mounted on deck without additional enclosing protection. (See Figs. 2, 7, and 8.)

Waterproof controllers may be used, but the usual practice is to enclose the entire control equipment in a waterproof case mounted on the winch frame nearby. (See Fig. 6.)

The equipment used has been reduced to its simplest form and has as few parts as possible, all of which are large and substantial. (See Figs. 3 and 4.)

The smaller devices are protected by being encased so that mechanical damage from outside sources is reduced to a minimum. Exposed parts are made weatherproof and are unaffected by climatic changes. This latter factor is of particular importance because, ordinarily, commercial carriers must call at all ports of the world. It is not unheard of that a vessel may leave one of the temperate Pacific coast ports and arrive at a Far Eastern port covered with ice, and with several cylinders of its steam-winch equipment cracked

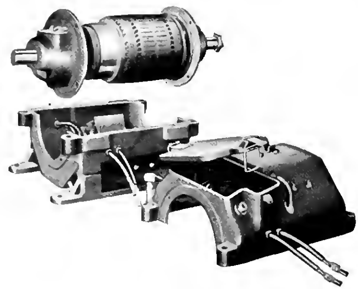


Fig. 3. View of Disassembled Winch Motor. Arrangement of parts facilitates dismantling

due to freezing of the condensation in the steam chest. It is also often necessary to keep steam winches turning over slowly in cold weather to keep them from freezing. Such precautions are not necessary with electric winches.

Speed of Handling

Unless simplicity marks the control equipment, miscellaneous stevedore labor cannot readily operate and handle the outfits without previous experience. Practically all such labor is experienced in operating steam winches. The control must therefore be similar to that of steam winches and, furthermore, must be simpler and more positive in order to at once win over the operator to the equipment. It is a new departure and, therefore, must immediately overcome the prejudice of lack of acquaintance and give the operator confidence in his ability to handle it. Experience has shown that a stevedore can operate electric winches to the satisfaction of himself and the loading crew after a few minutes of practice, and after a day's handling he is enthusiastic about the ease and positiveness of the control.

The requirements for fast loading and unloading are:

(1) Positive and uniform control of the load and the empty loading gear.

(2) High average speed of hoisting for all possible ranges of loads.

(3) High-speed hoisting both for the load and the empty loading gear.

(4) Positive control for lowering loads irrespective of the speed of lowering.

(5) Positive braking to stop the travel of the load quickly, so that full advantage may be taken of (4).

Easy control of the loading gear is essential to safety as well as to speed. Any reduction in the normal labor required for operation gives so much more time for the operator to watch results and interest himself in perfecting the niceties of handling which make for speed through eliminating false motions, such as, incorrect placing of load, running out more line than actually required (either empty or loaded), apparent inability to swing and stop load quickly over the exact position for lowering, etc., while hoisting.

This ease of control in electric winches is obtained by having the entire operation of hoisting, lowering, and braking for each drum controlled by a single lever (see Fig. 6). The position of this lever controls the speed of the outfit and the brake is applied

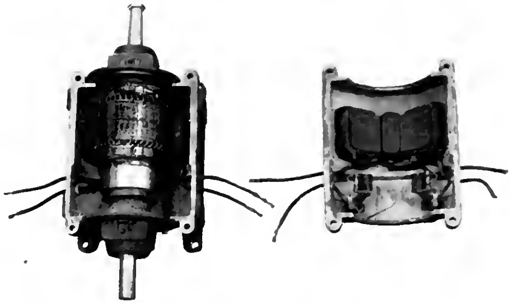


Fig. 4. Motor with Top Half of Frame Removed. Interior of motor easily inspected, two main poles, and one commutating pole in each half of frame

by moving the handle to the *off* (central) position. This is analagous to the throttle control of steam winches, with the added advantage of controlling the brakes which, with the steam outfit, is a separate operation.

To obtain the best results, the operator must know that the same position of the control handle will always give the same definite results. With electric winches, this is secured by properly choosing the size and type of the generating equipment and its prime mover, and by the correct layout of the distributing circuits to the several winches. The uniform performance of the motors requires uniform voltage at the motor terminals. This is easily obtained under the conditions just named. In actual loading operations the voltage range has been observed to be about 2½ per cent to 5 per cent, the latter obtaining for sudden changes of load that cause instantaneous fluctuations, while the maintained voltage after this sudden drop is about 2½ per cent to 3 per cent below no-load voltage. An item favorably influencing voltage regulation is the relatively short lengths of circuit from the generating outfit to the winches so that the current-carrying capacity of the wires, rather than the voltage drop, is the limiting feature for the size of the winch.

For equivalent uniform control of steam winches, some of the principal items to be considered are:

(A) Steam pressure and quality.
(B) Exhaust pressure.
(C) Piston and valve fit.

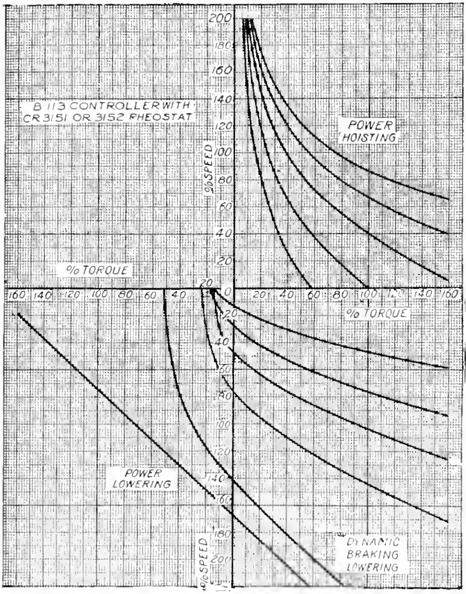


Fig. 5. Speed-torque Curve showing Hoisting and Lowering Control for Cargo Winches

Unless steam pressure and quality are maintained at normal values there is a marked reduction in speed of the outfit when loaded and in the size of the load that can be handled. Even with maintained pressure the speed regulation for a given valve position with varying loads is not so good as that of the electric winch. The load handled has a marked effect on the back pressure, due to the limitations of exhaust port area. The back pressure is greatest when the load is heaviest—an unfavorable condition in itself.

The number of winches operating at one time has a decided effect on both initial and exhaust pressure, so that one winch running alone may perform excellently; but should two or three others pick up heavy loads at the same time, none of them can approach their maximum capacity owing to drop in pressure in the steam line. Of course, extra boiler capacity and large steam and exhaust lines will ameliorate such a condition, but here enter the questions of first cost, space, and operating cost, and we are considering only average conditions as found, not the best conditions which could be produced with a view of showing the steam winch to best advantage without regard for cost, space or boiler room operation. This point is touched on later under cost and operating efficiency. Therefore, unless there is uniform control under all conditions of operation, the highest average operating speed cannot be maintained since the operator is constantly crowding or holding back the outfit, never knowing exactly what to expect of it.

High lowering speed, whether loaded or light, and positive control during lowering are obtained by applying the principle of dynamic control. Here, the motor is either acting to hold back the load or assisting in lowering, depending upon the weight of the load and whether, as the result of gravity alone, the load would seek a speed higher or lower than that which the operator wishes. In both cases, however, the motor is connected to the power circuit, and a balance is struck between the speed of load and the effort exerted by the motor. Fig. 5 shows the typical characteristics of such control conditions. The operator, having control of the load at all times and "feeling it," as it were, can maintain a higher rate of speed than would be safe under other conditions. The scheme of lowering gives the flexibility necessary to eliminate sudden jerks in the hoisting cable, there being no tendency to have any slack in the cable with this method of control. To have positive control it is essential that there be no sudden or irregular jerks on the cable.

Positive braking allows the operator to spot the load or empty hook accurately, lower at maximum rate until almost in place, and stop quickly and positively without smashing the load. It also permits very small adjustments of load just before making a landing to permit easy landings in the exact spot required. This feature of electric operation is appreciated by the operators, and in every case calls forth favorable comment.

Cost and Efficiency of Operation

As to cost and efficiency of operation, the electric winch outfits compare favorably with steam installations. Earlier, it was stated that activity in the auxiliary motor-ship construction gave electric winches an opportunity of demonstrating their worth. The propelling equipment of these vessels are crude oil engines, so that no boiler plant is required. Any boiler plant installed on such vessels is for the winches only, so that a direct comparison is easily obtained between the first cost of a steam installation and an electric equipment. These costs are so nearly the same that the great operating economies of the electric method at once decide its choice; in fact, estimates indicate that the electric installation is actually slightly cheaper. The prime mover for the generator in such installations has been a crude oil engine, and when the cost of such units is compared to the cost of small steam turbines or engines, a large reduction is shown in first cost for a vessel with steam plant as compared to motor equipped ships.

The operating costs are low because of the ruggedness and simplicity of the equipment, and the small amount of attention required. With the electric outfit power is generated only when required (except for the small rotation losses of the generating unit) and is transmitted to the winches effectively. There is no loss comparable to the stand-by losses of a boiler when the units are idle, or to the leaks and condensation in steam line and at winches, whether running or idle. The fuel saving is a considerable item. The economy of a central generating unit is better than that of six or eight or more individual smaller units. The economy of prime movers improves as the size increases, and limitations of design decrease. One unit furnishing power to several sources of fluctuating load has a better average load and economy than separate units at the several points. The steam winch engine is an uneconomical steam user, as not so much consideration is given to its design with a view to economy. The modern electric generating set is an economical unit and every consideration is given to its economy as well as to its reliability and safety.

These are among the considerations that make the saving in operating costs with electric winches a considerable item. In fact, in the case of the motor ship the saving is sufficient to pay the entire cost of the electric installation in eighteen months. If to

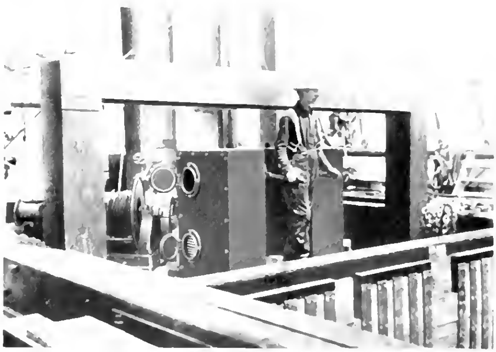


Fig. 6. Deck Control Position in Front of Hatch, showing Method of Winch Control

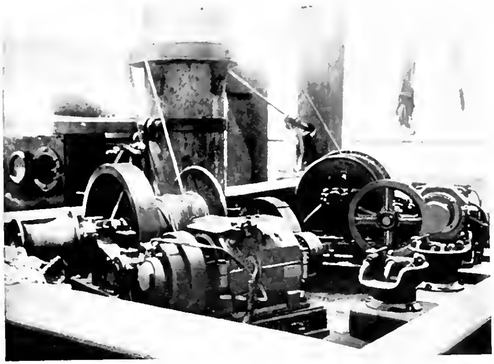
this are added the difference in upkeep and supply material costs between steam and electric installations, the electric winch will be put in a still more favorable light.

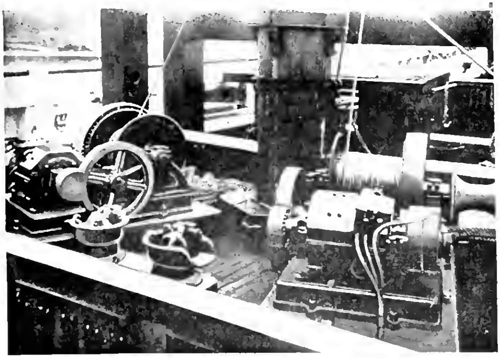
Unfortunately, too much consideration is given to the item of the first cost and too little to the operating costs. Unless both the builders and purchasers have given proper consideration to all items of cost and are working in harmony for the best results, a short-sighted policy, detrimental to one or the other, is likely to be adopted.

The total cost of the complete winch installation, whether steam or electric, will not exceed 6 per cent of the cost of small vessels, or 3 per cent of the cost of larger vessels. (Small vessels are classed as 2000 tons net cargo and less, large vessels as 3000 tons net cargo and larger.)

The choice between the two schemes of winch drive will not affect the cost more than 10 per cent either way from an average. Thus there may be a maximum difference in cost of 20 per cent for the winch installation, or 1.2 per cent of the total first cost for a small vessel, and 0.6 per cent of the first cost for a large vessel. The effect of this on total operating costs is negligible and, therefore, the question of first cost, insofar as it affects a decision between steam and electric winches, may be eliminated from consideration.

The speed of loading has been mentioned—such comparisons of necessity covering the same class of work to be performed under the same climatic and other conditions. With inexperienced operators loading miscellaneous lumber in unfavorable weather (six inches of snow on dock and lumber piles, with the snow thawing), operating three hatches with two single drum winches at each hatch, approximately 25 per cent more lumber than is the usual estimate for steam winches operating under favorable conditions was loaded the first day the electric outfits were run. Subsequent loadings have been made with greater dispatch. Further information along this line will be available within a short time, as additional complete loading and power records are to be taken on a later vessel in the near future.





Figs. 7 and 8. Electric Winches Mounted on Deck

Fig. 10 shows a long timber being lowered into the hold.

The winch equipments which have been specified by builders cover light, moderate, and heavy duty hoists. All of them consist of:

(1) Generating equipment,
(2) Switchboard equipment,
(3) Winch motors and control,
(4) Anchor windlass motor and control,
(5) Miscellaneous motors.

These will be considered in the reverse order because of the control of the last items in deciding upon the type and capacity of the first two.

5. Under this heading come motors for miscellaneous pumps, machine shop, refrigerating plant, etc., which need no comment.

4. *Anchor Windlass Motor:* The size of this motor varies with the size of anchor and chain, and also length of chain. It is usually geared to the hoisting drum through double reduction gearing—one step being a worm drive and consequently not reversible except by the application of power. No electric brake is needed, although usual practice contemplates a disk brake to provide for emergencies. Straight rheostatic reversible control is used, with a contactor reset protective panel for protection of the motor from a too severe overload or incorrect operation. The motors usually chosen are low speed, totally enclosed and weather-proof, and range from 25 h.p. to 50 h.p., depending upon the duty specified.

3. *Winch Motors and Control:* The motors are series wound, totally enclosed, weather-proof, commutating-pole motors of the most rugged mechanical construc-

tion and conservative electrical characterteristics. They are geared to the hoisting drum through either single or double reduction spur gearing. The front end of the motor shaft is fitted with an electric brake that instantly and automatically sets when the controller is turned to the "off" position. The brake releases only when the controller has been turned to the running position and sufficient current flows to operate the motor. This guards against the brake releasing, in case of an open circuit, and dropping the load. The brake is capable of holding any load that the motor will be called upon to lift. (See Figs. 2, 7, and 8.)

The control equipment, as has already been described, works on the dynamic braking principle, which gives absolute control of the load whether hoisting or lowering. This principle is not new and has been used for heavy crane work for some years. It is only by means of some such application that a nicety of handling heavy masses has been made possible.

An electrically reset protective panel is a convenient adjunct. It furnishes protection to the winch motors and, after being called upon to operate, may be reset by the operator without leaving his station.

The winches are usually located in pairs—two at each hatch; thus two motors per hatch are usually required. (See Figs. 7 and 8.)

The sizes selected are 15-h.p., 20-h.p., and 25-h.p. low-speed motors. The selection depends entirely upon the builders' specifications. As noted before, the specified requirements will be for loads and speeds covering a wide range, viz., 1500 lb. at 250 feet per minute, to 12,000 lb. at 75 to 90 feet per minute. In general, the average miscellaneous cargo carriers will call for winches capable of handling loads of 3000 pounds at 200 feet per minute. This is the basic rating. The equipment should, of course, be expected to handle light loads at higher speeds and heavier loads at lower speeds. Such an outfit should be capable of handling more cargo in a given time than can be stored in the vessel in an equivalent length of time. The equipment to meet the requirements is standard and readily chosen.

2. The switchboard should have all metal parts made of non-corrodible material, and should consist of the necessary panels to mount and properly control the different circuits. There should be one circuit for each hatch equipment,

Fig. 9. Long Timber Suspended in Position Preparatory to Lowering

one circuit for anchor windlass equipment, and the necessary circuits for miscellaneous motors so that those having no inter-relation may each have an independent circuit. The necessary overload protection must be provided in accordance with underwriters' requirements.

1. The generating equipment must have ample capacity to care for the heaviest loads that may be imposed upon it. The deversity factor is great however. The anchor windlass will practically never be operating at the same time as the winch outfits. Sudden high swings may be encountered, but these are of short duration. The fewer the number of hatches, the larger must be the generating unit in proportion to the total connected load. With three or more hatches all high swings of the load are of very short duration, one to five seconds. The generator should be compound wound, preferably

with a slightly rising characteristic at full load, and should be a commutating pole machine.

The prime mover may be a steam turbine, steam engine, gas engine, or oil engine, as conditions determine. The prime mover selected should have ample capacity to withstand, with good speed regulation, the heaviest loads that may be imposed upon the unit, otherwise the best voltage conditions cannot prevail. A number of such electric cargo winch installations have been made in the past year, all of which have proven eminently successful.

All of the remarks regarding electric equipment apply equally to both alternating- and direct-current installations.

In operation, it is sometimes desired to take in rope slowly to avoid a jerk on the load. This is somewhat similar to the jogging service for printing press drive. Special attention should be given to this feature if a-c. equipment is to be used. The first point of control with d-c. outfits can be adjusted so that such slow light work can be performed satisfactorily.

In choosing protective equipment, fuses should be eliminated as far as possible and the necessary protection afforded by means of electrically reset overload relays. With such an arrangement, it is not necessary for the operator to leave his position to replace fuses or to close a manually operated circuit-breaker.

A curve for direct current, showing the action of the motor at several points of both hoisting and lowering, is shown in Fig. 5.

Table I shows a standard line of direct-current motors which may be chosen for such work. The selection of the size and speed will depend upon the duty to be performed. This table gives the rating on a thirty-minute duty basis. In selecting a motor for any specific duty, consideration should be given to the average duty, as well as to the maximum load to be handled.

TABLE I

FRAMES AND STANDARD RATINGS OF CO-1800 MOTORS

Frames	Low Speed H.P.	Low Speed Revolutions per Minute 115 and 230 Volts	Low Speed Revolutions per Minute 550 Volts	Moderate Speed H.P.	Moderate Speed Revolutions per Minute 230 Volts Only	Approximate Net Weight in Lbs.
CO-1803	2	900	1000	3	1350	290
CO-1803	3	750	850	5	1200	290
CO-1804	5	725	800	7½	1200	415
CO-1805	7½	700	775	10	925	515
CO-1806	10	650	725	15	875	635
CO-1807	15	600	675	20	800	875
CO-1808	20	550	600	25	725	1125
CO-1809	25	550	600	35	725	1300
CO-1810	35	500	550	50	725	1800
CO-1811	50	450	500	65	600	2515

The limiting speeds for these motors are as follows:

CO-1803	3500 r.p.m.	CO-1807	2200 r.p.m.
CO-1804	3200 r.p.m.	CO-1808	2200 r.p.m.
CO-1805	3200 r.p.m.	CO-1809	2100 r.p.m.
CO-1806	2700 r.p.m.	CO-1810	1900 r.p.m.

The Suppression of Hysteresis in Iron-carbon Alloys by a Longitudinal Alternating Magnetic Field

By C. W. Waggoner and H. M. Freeman

Department of Physics, West Virginia University

The results of any investigations dealing with the hysteresis losses of iron and steel are of extreme importance in electrical engineering. In the following article the authors discuss some remarkable experiments on the disappearance of hysteresis due to the action of an alternating magnetic field.—Editor.

This article is a report on the preliminary study of the suppression of hysteresis loss in iron-carbon alloys when a longitudinal alternating magnetic field is superimposed upon a hysteresis cycle that is produced by a slowly varying direct-current field. The other physical properties of the series of iron-carbon alloys tested (hysteresis loss at 20 deg. and —190 deg. C., tensile strength, temperature coefficient of expansion, etc.) have been reported elsewhere.[1]

That there is a relation between the elastic and magnetic properties of such a series of alloys, and that this relationship might have been predicted from the Ewing molecular theory and the phase diagram for the microscopic constituents, has been pointed out heretofore.[2] It was shown that the magnetic hysteresis should increase with the percentage of pearlite in a series of carbon steels up to the eutectic percentage[3] and then decrease with the pearlite beyond the eutectic point.

The relation between the three constituents —ferrite, pearlite and cementite—is shown diagrammatically in Fig. 1. Ferrite (pure iron) and cementite (Fe_3C) unite in a definite proportion to form a closely interwoven and interstratified mixture called pearlite. At about $\frac{9}{10}$ of one per cent of carbon the whole mass is pearlite and every ferrite molecule is securely held by cementite. The iron carbide (cementite) has a specific magnetization of about one-tenth that of pure iron,[4] so that it may be assumed that the phenomenon of hysteresis has to do very largely with the ferrite molecule and its freedom of motion. In low-carbon steels, where ferrite is in excess, the hysteresis loss should be low. The loss should increase with the decreasing free ferrite molecules up to the eutectic point. Beyond the eutectic point, there is an excess of cementite; and, it is assumed that this net-work of excess cementite may break up the solid mass of pearlite and thus free some of the ferrite molecules. Any molecules thus freed should cause a slight reduction in the hysteresis loss at increasing percentages of carbon.

This particular study was made to ascertain, if possible, any connection between the freedom of motion of the ferrite molecules and the carbon percentages; it being assumed, at the outset, that the superposition of the longitudinal alternating magnetic field would produce a "shaking up" action on the ferrite molecules. It was hoped that such a study would furnish additional data to substantiate the foregoing theory.

The fact that a superimposed alternating field would produce, at high inductions, a suppression of the hysteresis loss is not new. The suppression caused by high-frequency alternating fields has been thoroughly investigated in connection with the magnetic detector for radio-telegraphy, and a summary of this literature has recently been made by Bown.[5] Fleming and Coursey[6] working with soft iron wire have shown that in strong fields ($H = 8$ or more) the hysteresis loss is

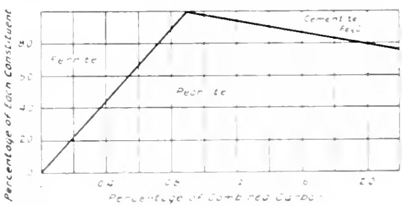


Fig. 1. Curve showing the Constitution of Iron Carbon Compounds

diminished by the application of alternating fields, for high and low frequencies, and for either longitudinal or circular fields; also that, in general, the effect of either longitudinal or circular alternating magnetic force, damped or undamped, is to increase the value of B_{max}. N. H. Williams[7] using a Koepsel permeameter and working with cross-magnetic fields finds that for soft iron the hysteresis loss disappears entirely, and that for steel the loop is greatly reduced by the application of the cross-magnetic alternating

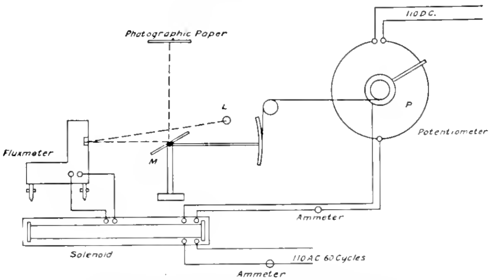


Fig. 2. Diagram of the Apparatus used in Obtaining the Hysteresis Loops while the Test Sample is acted upon by a Longitudinal Alternating Magnetic Field

fields. He also finds that, for soft iron, B_{max} is reduced by the cross alternating field, while for hard steel it is increased beyond the normal value.

The chemical analysis of the steels used is given in Table I. With the exception of the sample marked "ARCO" they are the same samples as were used in obtaining the hysteresis loss at low temperatures. The heat treatment of these samples has been described in the results of a previous investigation.[8]

The method of obtaining the hysteresis curves was a modification of a method used

TABLE I
CHEMICAL ANALYSIS OF THE IRON-CARBON SAMPLES

Identification Mark	Carbon	Phosphorus	Silicon	Manganese	Sulphur
ARCO	0.01	0.005	0.005	0.025	0.025
P.I.	0.058	Trace	0.008	0.071	—
A1	0.60	0.013	0.15	0.14	0.012
A2	0.74	0.012	0.16	0.14	0.013
A3	0.89	0.010	0.19	0.155	0.013
A4	0.98	0.012	0.16	0.15	0.013
A5	1.18	0.012	0.14	0.14	0.013
A55	1.26	0.012	0.16	0.17	0.014
A6	1.37	0.011	0.19	0.16	0.012

by Fleming and Coursey; the principal change being in the substitution of a Grassot fluxmeter for the magnetometer in determining the flux. The apparatus is shown diagrammatically in Fig. 2, in which P is a simple slide-wire potentiometer of nichrome ribbon having a rotating contact which furnishes the slowly varying magnetizing currents. A cord, fastened to a pulley wheel on the potentiometer, is attached to a lever which serves to give the mirror M an angular displacement directly proportional to the magnetizing current, and hence causes the spot of light from L to trace out on the photographic paper the H displacement of the B-H curve.

The B displacement is produced by the light reflected from the mirror of the flux-meter which is connected to the secondary of the magnetizing solenoid. The source of light L was a Mazda C automobile headlight lamp and, when brought to a sharp focus on the photographic paper by the fluxmeter's concave mirror, gave a very satisfactory trace as is shown in Figs. 3, 4, and 5, which are reproduced from the actual photographs obtained by this method. Insurance bromide, Grade B, photographic paper was used, and it was found by trial to be the most satisfactory for this purpose. The solenoid is one meter long and is wound so that for a current of one ampere H is 35 c.g.s. The wire for the alternating-cur-

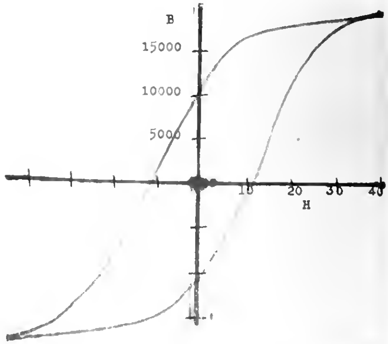


Fig. 3. Photograph of the Normal Hysteresis Loop for Sample P1

rent field was wound on a glass tube and was placed inside the direct-current winding. The samples of iron, 40 cm. long and approximately 0.5 cm. diameter, were placed inside the glass tube and then carefully centered in the solenoid.

With all the dimensions given for the solenoid, it is a very easy matter to calibrate the apparatus so that it will read B and H directly. The H displacements are functions of the direct current only. The B displacement was determined by keeping the oscillating mirror M quiet and passing a known current through the direct-current coil of the solenoid without iron. The magnetic flux causing the ballistic throw of the flux-meter can be readily calculated.

In this preliminary study two hysteresis curves were taken for each sample; one the normal curve and one with the 60-cycle longitudinal alternating field. The areas of the hysteresis curves thus obtained were measured by a planimeter, and the suppression of the hysteresis loss was calculated from these areas.

In order to insure all cycles being made in the same time, the movement of the contact arm of the potentiometer was timed by a metronome and the cycles were all taken in four seconds or as near this time as was possible.

For purposes of strict comparison, the same H_{max} direct current was used in each case as well as the same H_{max} alternating current. These values were: H_{max} direct current = 42.3 c.g.s., and H_{max} alternating current = 58.7 c.g.s., and were sufficient to produce a magnetization well over the "knee" of the magnetization curve. Figs. 3, 4, and 5 show the character of the curves taken by this

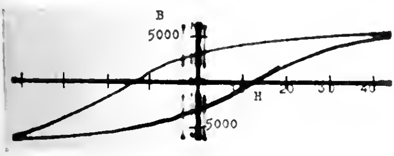


Fig. 4. Photograph of the Normal Hysteresis Loop for Gray Cast Iron

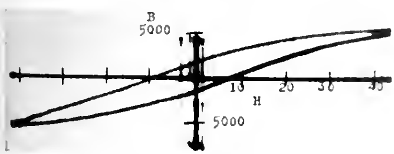


Fig. 5. Photograph of the Hysteresis Loop for Cast Iron with the Alternating Field Impressed upon the Loop

method. Fig. 3 shows the normal curve of hysteresis with Sample PI. Figs. 4 and 5 were taken on a sample of good gray cast iron and show the characteristic curves for cast iron as well as the dimunition in hysteresis caused by the superposition of the alternating-current field. Some curves were taken on a sample of Invar, also on a high-carbon magnet steel commonly used in telephone receivers

The results are condensed and shown in Fig. 6. This curve shows that, in general, the effect of the impressed alternating-current

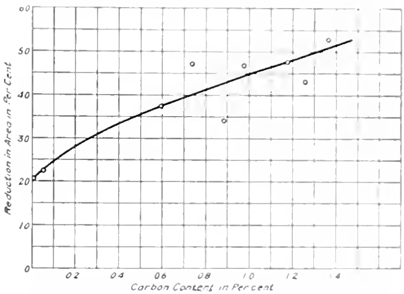


Fig. 6. Change in Area of Hysteresis Loop with Variation of Carbon Content. Annealed Magnet Steel, 38.8 per cent; "Invar" 27.8 per cent; Cast Iron 44.5 per cent

field is to produce a reduction in the hysteresis loss for all the alloys, the effect being greater in those of highest carbon content. The data in these preliminary tests do not warrant any conclusions other than that the effect of the impressed alternating-current field causes a suppression in the hysteresis which is a more or less direct function of the carbon content.

Contrary to the assumptions at the beginning of this study, the results indicate that the suppression of hysteresis by longitudinal alternating magnetic fields cannot be likened to the suppression obtained by mechanical vibrations. According to Ewing[9] "In experiments of the same class with hard iron or with steel, vibrations (mechanical) produce effects of the same general kind; but its influence in destroying hysteresis is far less complete than in soft iron." It would appear from the results described in this article that the two effects are exactly opposite, so far as the composition of the material under test is concerned. It is, however, possible that the explanation is to be found in the action of the eddy currents induced in the samples during the alternating-current magnetization and this point is being investigated at the present time

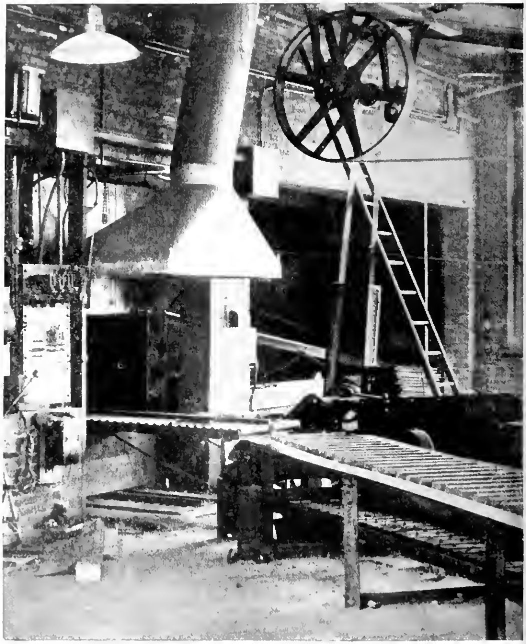
(1) Waggoner, Phys. Rev., vol. xxviii, p. 303, 1909.
Jones and Waggoner, Proc. Am. Soc. for Testing Mat., vol. xi, 1911.
(2) Waggoner, Phys. Rev., vol. xxxv, p. 58, 1912.
(3) About 0.9 per cent carbon
(4) Honda and Murakami, Science Abstracts, vol. xx, No. 1026, 1917.
(5) Bown, J. Franklin Inst., vol. clxxxiii, p. 42, 1917.
(6) Fleming and Coursey, Proc. Phys. Soc. Lon., vol. xxviii, 1915.
(7) Williams, N. H., Phys. Rev., vol. ix, p. 339, 1917.
(8) Waggoner, loc. cit.
(9) Ewing, Magnetic Ind. in I. and Other Metals, 1900, p. 118.

*Electric Oven for Baking Cores

The electrically heated drying oven possesses a decided advantage over steam-heated or gas-heated ovens in that the temperature may be regulated to a nicety, and when once the thermostats are adjusted for a given operation the equipment is automatic and requires very little attention. The electric oven has established itself in high favor with automobile manufacturers, and some of the principal installations have been with these concerns, for drying enamels, cores, etc. The results that are being obtained by the use of an electric oven for baking cores at the plant of the Wyllis-Overland Company are outlined in this article.—EDITOR.

Electricity for heating a core oven is being successfully used in the first oven of this type that was recently installed in the aluminum and brass foundry of the Willys-Overland Co., Toledo, Ohio. One electrically heated oven has been in use several months, and the erection of a second oven of a similar type, for larger cores, was started recently, but it is not completed at this writing. The two ovens are located side by side under the roof of one of the core rooms in which ovens of the standard type are used. One of the electric ovens is 20 ft. above this core-room floor and the other is 5 ft. higher.

The ovens are of the continuous conveyor type, and each has a vertical leg of the same section, 20 ft. long, at the front of the oven, extending to the floor, in which doors are provided for loading and unloading the cores. The oven in use is 45 ft. long, and the new one is 60 ft. long. They are 10 ft. 8 in. in height and 5 ft. 6 in. in width, being built in two sections, with a 2-in. asbestos partition between the upper and lower sections. The framework is of steel, and the first oven has asbestos walls 2 in. in thickness on the four sides. The second oven is covered on the four sides with Nonpareil insulating brick. The ovens are supported by steel trusses on which is laid a a floor or platform of steel plates. Other steel trusses carry the conveyor machinery in the ovens, so that the supports of the ovens and their conveyors are entirely independent.



Cores placed on cast-iron plates are carried into the oven on a roller platform and the plates are pushed upon a shelf in the conveyor carriage. After passing through the upper half of the oven and back through the lower, the cores are carried by the conveyor through a vertical section of the oven to the lower floor where they are removed.

Cores baked in the continuous electric ovens are made on a second-floor core room, at one end of which at a convenient height above the floor for loading, are the oven doors. Beneath the core room is a sand storage room, from which core sand is carried up in a bucket elevator. A roller chain conveyor, 100 ft. long and 24 in. wide, extends the length of the second-story core room through the center, terminating near the entrance to the oven. This is shown in the illustration. The core-room makers' benches are located on both sides of the conveyor, and when they

* [illegible]

finish their cores they put them on plates or trays which are placed on the conveyor and thence are carried to the oven. The trays are flat sections of cast iron, 14 in. wide and 30 in. long, having numerous circular perforations to allow the free circulation of the hot oven atmosphere. Usually, two or three cores are placed on one tray, the number depending on the size. The cores remain on the trays until removal from the oven.

The movement of the core-room conveyor, which is not in continuous operation, is controlled by a push-button by an operator who stands at the end of the conveyor. This operator lifts the tray of cores from the conveyor and places it on a short section of a roller platform built on a slight incline, over which he pushes it into the oven conveyor, the tray fitting into an angle-iron shelf in a carriage or rack in this conveyor. The carriages, which are pivoted to the conveyor on 5-ft. 6-in. centers, have double rows of shelves, each carriage having eight shelves on each side. The conveyor is 126 ft. 6 in. long, and has 23 carriages. The second conveyor, for large cores, has four carriages on 5-ft. centers, but only four shelves on each side.

The travel of the cores, after being placed on the conveyor at the loading door, is upward to the top half of the oven, from the front to the back of the oven, back through the lower section, and down a vertical section of the conveyor to the lower floor, where the baked cores are taken out. Here a short section of roller platform is provided for handling the trays and cores, similar to that at the loading end. The conveyor carriages pass on and up to the loading end of the oven, again to be filled. After the cores are taken from the conveyor trays the latter are placed on a 12-in. belt conveyor with steps bolted to it for carrying the trays to the second-floor core room.

The conveyor travels at a speed of approximately 9 in. per minute, and is driven by a 5-h.p. motor. It takes 2 hr. 5 min. for the cores to pass from the loading end to the discharge end of the oven, the conveyor making the complete circuit in 2 hr. 40 min. The time required in the new oven will be slightly longer, owing to its greater strength. Large cores have been baked in the first oven pending the completion of the larger oven, these being allowed to make two circuits through the oven instead of one circuit. The capacity of the oven for small cores is approximately sixteen trays of cores every 7 min. It has proved of sufficient capacity to bake all the cores made by its sixteen core makers, although on the average it will handle the output of twelve men. With the completion of the new oven all the cores made for the foundry will be baked in two electric ovens.

The heating units are distributed all through the ovens, in both the lower and upper sections. The cores are dried off in the upper half of the oven, and are baked in the lower half, where the temperature is higher, and cooled off somewhat while passing through the vertical section on their way to the discharge door on the lower floor. A 30-in. stack, 20 ft. high, controlled by a damper, is located above the front of each oven to carry away the gases, which travel in a direction opposite to the movement of the conveyor. The conveyors and steel frame supports for the ovens were supplied by the Link-Belt Co., and the ovens were built by the Young Brothers Co.

There are about 21 heating units in the oven, of General Electric make, with a rating of about 8.2 kw. each. Nine are controlled by a hand-operated switch, and the remaining twelve are on a circuit controlled automatically by a Brown pyrometer. The heat is thrown on the oven by the watchmen at 5:30 a.m., and this allows about two hours for the oven to get up temperature before the core makers start to work.

In the table are given the results of a test of the oven, made recently by a representative of the power company supplying current for the plant.

Supplementing the figures showing the results of the test, the following statement was made:

"The results of this test are indicative of continous operation since the oven was up to operating temperature when the test was begun.

"The heat required for the operation is that to bring the cores up to temperature, to drive off the moisture, to bring the plates up to temperature, to heat the ventilating air, and to supply the losses through the walls and through metal. There is also a loss of heat by the larger cores while passing through the vertical leg of the oven, as they are returning to go through the horizontal leg the second time. Since the large cores have to be sent through the oven twice, the production is cut down.

Test of the Electrically Heated Core Oven

Duration of test, min	320
Average temperature of operation, deg. Fahr	386
Cores baked, lb	6,907
Electric power, kw. hr	915
Pounds of cores per kw. hr	7.55
Kw-hr. per pound of core	0.1324
Moisture in the sand, 6 per cent assumed, lb	415
Heating moisture, 415 × (326 + 966), B.t.u.	536,180
Heating sand, (6,907 − 415) × 0.45 × 326, B.t.u.	952,376
Total heat to bake neglecting air, B.t.u.	1,488,556
Heat input, 3,412 × 915, B.t.u.	3,121,980
Thermal Efficiency, per cent	47.68
Radiation per hr., 1,009 × 0.25 × 326, B.t.u.	82,234
Total radiation during test, B.t.u.	438,304
Heat absorbed by plates, B.t.u.	221,940
Total heat accounted for, B.t.u.	2,148,800
Heat consumed by air and through iron, the amounts of which it was not feasible to ascertain, B.t.u.	973,180

"The heat required for absorption by the iron entails a loss of 24 kw. per hour with the present 2-in. insulation. With 4 in. of insulation this loss would be only one-half as great.

"The heat required for absorption by the iron plates is 41,640 B.t.u. per hour. or 12.2 kw. hr. If these plates were made of aluminum, of the same size, the heat required for absorption would be 26,500 B.t.u. per hour, or 7.77 kw. hr."

Some Factors Affecting Determination of the Maximum Demand*

By Chester I. Hall

Fort Wayne Works, General Electric Company

A concise review of the development of maximum demand rate systems is given in the introduction of the article below. This is followed by a discussion of the four general methods of measuring the maximum demand made on central stations by consumers. Maximum demand meter requirements are segregated into two subdivided classifications and the corresponding types of meters are named. What constitutes an equitable time interval over which to integrate demand values is given consideration in the conclusion of the article. A companion article on maximum demand meters will appear in an early issue.—Editor.

In 1892, Doctor John Hopkinson, of Manchester, England, propounded what was at that time a startling theory, viz., that the charge for the electrical service rendered should bear some relation to the cost of rendering it. This general thought led to the analysis of central station costs, and to the development of a great number of different kinds of rate systems. Dr. Hopkinson immediately applied his theory in a rate system, having as its primary object a uniform use of current for as many hours per day as possible, on account of the obviously profitable nature of this class of business.

The application of this system called for an initial payment by the customer of an amount dependent upon the maximum consumption which the customer would guarantee, and an additional charge dependent upon the number of kilowatt-hours used during the period. This system was found to have marked limitations, and in 1902 Arthur Wright, of Brighton, England, amplified and refined Dr. Hopkinson's ideas and developed what is known as the maximum demand system, having a primary and secondary charge. The primary charge, which is generally larger, is based upon the maximum demand which the customer draws from the central station, and the secondary charge upon the kilowatt-hour consumption. Wright went further and developed instruments for measuring the charge, resulting in what we have been using in America as the Wright Demand Meter.

At about this time many of the disciples of Dr. Hopkinson were giving very intensive thought to the application of such tariff systems, prominent among whom was Charles H. Merz, who believed thoroughly in the primary and secondary charge, but disagreed with Wright in the method of measuring the maximum demand for obtaining the primary charge. Merz contended that the measurement of maximum demand by instrument operating upon the logarithmic law was markedly unfair in certain instances, but that a definite mathematical average of the load conditions would be equitable to all classes of customers. This conception led to the development of demand meters operating upon

* Presented at the General Meter Conference of the Ohio Electric Light Association, Dayton, Ohio, November 23, 1917.

the principle of the integration of energy consumption over a definite time interval.

Since that time most of the development has been concerned with the application to existing conditions of the Hopkinson and Wright ideas, and to the development of accurate and reliable demand meters which will make such systems practicable. At the present time there are four general methods of obtaining a measure of the primary charges which are in more or less active use:

1. The observation of instantaneous indicating instruments.
2. Observational averages obtained by stop-watch readings of watthour meters, or the integration of charts of instantaneous graphic recording instruments.
3. Demand meters operating upon the lagged or logarithmic principle.
4. Demand meters giving the result of integration over a definite time interval.

It is quite obvious that some of these systems give erroneous readings under many normal operating conditions, and upon loads other than those of constant value.

In order to standardize and give a reference point from which measurements of maximum demand may be compared, the central station organizations of this country have settled upon the following definitions for demand, load factor, and diversity factor:

The *demand* of an installation or system is the load which is drawn from the source of supply at the receiving terminals, averaged over a suitable and specified interval of time. Demand is expressed in kilowatts, kilovolt-amperes, amperes, or other suitable units.

The *load factor* of a machine, plant, or system is the ratio of the average power to the maximum power during a certain period of time.

The *diversity factor* is the ratio of the sum of the maximum power demands of the subdivisions of any system, or parts of a system, to the maximum demand of the whole system, or of the part of the system under consideration, measured at the point of supply.

In order to clear up many misconceptions relative to the various methods of measuring demand, the curves of Fig. 1 will be of value.

1. Instantaneous demand.
2. Lagged or logarithmic demand.
3. Integration over a definite clock time interval.
4. Integration over an elapsed time interval.

There are two methods by which the classification of demand meters can be made: first, with respect to the kind of customer or size of installation; second, with respect to the

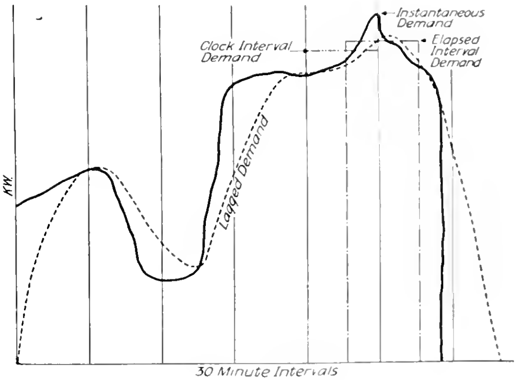


Fig. 1. Different Bases for Measuring Maximum Demand

amount or variety of information desired. It is, of course, impossible to make hard and fast rules which will apply in every case, as the installation of devices of this nature is regulated very largely by local conditions, both operating condition and those imposed by contracts. It is, however, possible to make more or less accurate subdivisions under a classification, and the tabulation below will serve to indicate a generally accepted basis in use at the present time:

(a) Loads up to 1 10 kilowatt.
(b) 1 10 kilowatt to 2.5 kilowatts.
(c) 2.5 kilowatts to 50 kilowatts.
(d) 50 kilowatts to 100 kilowatts
(e) From 100 kilowatts up.

CLASSIFICATION WITH RESPECT TO INFORMATION REQUIRED

(a) Applications requiring accurate limitations of demand.
(b) Applications which require indication of watt or kilowatt demand, without indicating time of day at which demand occurs.

(c) Applications requiring a permanent record of all of the demands of the month, together with the time of day at which each demand occurs.

(d) Applications which require the information as listed in class (c), but which require, on account of the large size of the installation, great accuracy of reading and permanency of record.

NOTE.—The two subdivisions (c) and (d) cover the problems connected with off-peak rate systems: contracts calling for the average of the three highest demands of the month, and similar special conditions.

There are available at the present time demand meters which fulfill the conditions set out in the previous tabulation. They may be roughly classified as follows:

1. Demand limiters.
2. Indicating demand meters giving integration over definite time interval. Lagged and logarithmic values of demand.
3. Curve drawing demand meters, including those giving instantaneous values and values integrated over definite time interval.
4. Printing demand meters.

In the application of demand meters one of the most troublesome and much discussed points has been the time interval over which the integrations are to be made. It would be obviously unfair to penalize a customer for an instantaneous overload, such as is caused by short-circuited conditions or other accidental reasons. If the time interval is made excessive, then during the interval large demands may be made upon the central station equipment, which would influence either the regulation of the line, or the capacity of the equipment necessary to serve such demands. The problem has been to arrive at some happy medium which would be equitable to both the central station and the customer. A general statement of the ideal condition is: The time interval should be so proportioned that only those demands which have an effect upon the central station operation or equipment are recognized and should be measured in proportion to their effect upon such operation or equipment.

This problem was first fully discussed by Mr. Louis A. Ferguson, of the Commonwealth Edison Company, of Chicago, in a paper entitled, "Effect of Width of Maximum Demand on Rate Making." Since that time many very careful investigations have been made upon actual service installations of many kinds, in order to determine the effect of various time intervals upon the value of demand obtained.

A compilation and analysis of the results of tests made by different central station companies under varying conditions will be illuminating in connection with the application of demand meters. While average variations will not necessarily indicate the actual differences to be found upon any specific customer by variations of the time interval, yet it is probable that the values given will roughly indicate the effect of such variations upon the revenue of the central station, which will be affected by all classes of customers.

Kilowatt Demand in Percentage of Thirty Minute Demand — Demand Interval				Connected Load in Percentage of Thirty Minute Demand
5	15	30	60	
108.4	104.4	100	97.3	209

It is of interest to analyze the data further with relation to the general classification of customers, in order to determine roughly those classes for which the variation is greater than the average, and those for which the variation is less than the average.

Class of Customer	Kilowatt Demand in Percentage of Thirty Minute Demand — Demand Interval				Connected Load in Percentage of Thirty Minute Demand
	5	15	30	60	
Light Manufacture	108	103.8	100	98	193
Heavy Manufacture	106.2	104	100	97	178
Automobile Manufacture	108	103	100	99.2	211
Foundry	110.7	108	100	97	292
Wood Working	107	102.3	100	94.5	199
Grain Elevator	110.5	105.5	100	98	194

Electricity in Logging and Saw Mills

By E. H. Horstkotte

Power and Mining Engineering Department, General Electric Company

Lumber mill machinery covers a relatively extensive floor area, owing to the necessity in some operation of passing back and forth long strips of lumber. Where steam power is employed this condition necessitates long lines of shafting, with its high factor of friction and consequent low efficiency. With individual drive of wood-working machinery by electric motors operated by central station service, the heavy loads that are constantly demanded by band saws, edges, etc., do not produce a serious drop in the speed of the entire equipment as is the case where power is supplied by an isolated power house of limited capacity. A particularly satisfactory arrangement is illustrated by the power equipment of a large lumber mill in the West which burns sawdust under boilers to operate electric generators that are tied-in with the power system of the local public utility for mutual exchange of power when conditions require.—Editor.

Logging

With an ever increasing demand for lumber and the necessity of logging in the more inaccessible places in our forests, there has been a continually increasing cost in bringing the logs to the mills. A large portion of this cost consists in gathering or yarding the logs along some railroad or river bank in the woods. Formerly this was done by the slow moving ox team. Increased demand for lumber, however, called for a more rapid and cheaper method, and as a result the powerful steam donkey was developed. Superseding this there came the electrical logging engine which, after five years of the most conclusive tests, has proven that where electrical energy can be transmitted at a reasonable cost, it is as superior to the steam donkey as the steam donkey is to animal power.

Performances of the electric donkey taken during the past few years have shown that when compared with other methods of logging, the electrically driven outfit will handle logs at a decreased cost per thousand feet and at an increased rate per day. It also has the following distinctive features:

Will safely withstand the severe service to which it is subjected.

Can transport itself through the woods.

No fires to build or water to haul.

No wood to cut and consume, using timber which could otherwise be converted into a commercial product.

No boilers to freeze or explode.

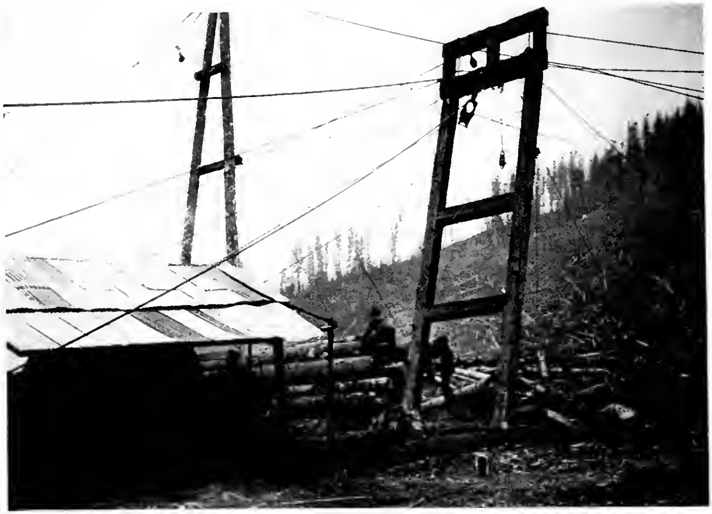
Eliminates sparks which are the source of many forest fires.

The power is usually transmitted at 11,000 or 22,000 volts from the generators located

Log Pond and Mill, Standard Lumber Company, Deer Park, Washington at the mills, where there is always an abundance of cheap fuel, to a portable substation located in the area which is to be logged. At the substation the voltage is stepped down, and is transmitted to the driving motor on the donkey through a flexible, three conductor armored cable. This cable is made up of sections 250 to 500 feet in length. The ends of the cable are provided with couplings by means of which extra lengths of cable may be readily inserted when it is desired to move the donkey.

Sawmills

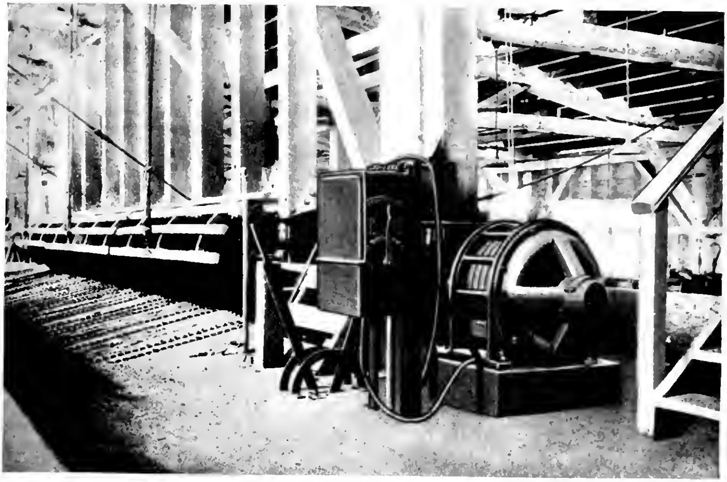
After a decade of operation, often under most severe service conditions, the electric drive in saw mills has proven its value whether in the cutting of the giant firs of the Pacific Coast, the pines of Minnesota and the Rocky Mountain states, or the hard woods of the South. Mill owners and designers, who in the early days took the risk of installing motors, are now firmly convinced that the induction motor, when properly designed and applied, is fully able to meet every demand imposed by this class of work. Its advantages over the slow speed steam engine with its accompanying line shafts, belts, and bearings are many.



Electric Logging Engine, showing Main Supporting Tower for Sky Line and Loading Boom, operated by 150-h.p., 550-volt Slip-ring Induction Motor. Potlatch Lumber Company, Elk River, Idaho
(A Sky Line is an overhead tramway for getting logs across a canyon)

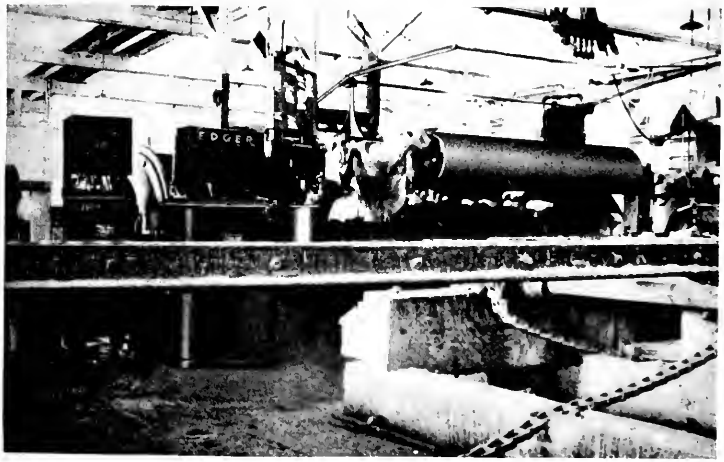
The motor equipment consists of a wound rotor, 60 cycle, 3-phase motor of standard voltage direct connected to the drums through gearing. The motor is equipped with a solenoid operated brake for quick stopping and to prevent any over-winding of the cable. In order to prevent the possibility of mechanically overtaxing the cable, each equipment is provided with an oil switch having an inverse time limit overload relay, set to give a practically instantaneous trip when the pull in the cable reaches some predetermined value. By this arrangement there has been a decided decrease in shutdowns due to the breakage of the cable; also the life of the cable has been greatly increased.

In a modern electrically driven sawmill, the non-condensing engine has been supplanted by a high speed, highly efficient condensing steam turbine, this change resulting in a great saving in boiler capacity, steam consumption, and floor space. All line shafting and large belts are practically eliminated, thus removing many obstructions to the lighting, and allowing a better distribution of machinery, with a marked reduction in the construction cost. The elimination of a large number of bearings reduces the fire hazard from hot boxes,



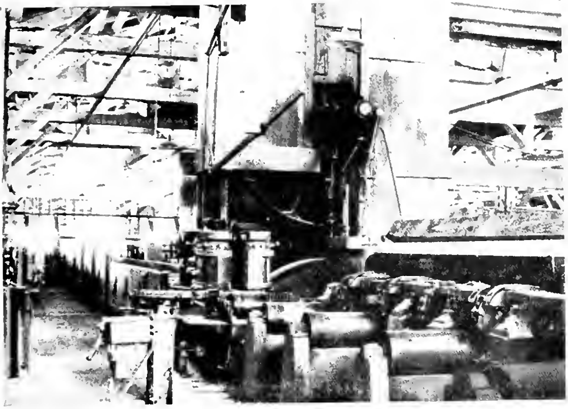
42-ft. 10-Saw Wood Slasher for Cutting Slabs into 4-foot Lengths for Fuel. It is Driven by a 75-h.p., 550-volt Direct-connected Motor. Weyerhaeuser Timber Company, Everett, Wash.

which has a very noticeable effect upon the insurance rates. A comparison of the quantity of oil required by steam and electrically driven mills of the same capacity shows that there is a large saving in this item. This is evident when it is considered that oil used in induction motor bearings is used over and over again, whereas that used on line shaft



12-in. by 72-in. Edger, showing Feed Roll Control and Starting Compensator Mounted on Edger Frame Weyerhaeuser Timber Company bearings is used once and they require oiling every day.

When sudden peaks, such as are continually demanded by band mills and edgers, are thrown on an engine there is a slowing down in the entire mill amounting to as much as 5 per cent or 7 per cent and sometimes up to 10 per cent on a poorly regulated engine. When electrical drive is substituted this cannot occur, as each machine has its individual drive, and when these heavy peaks are demanded the only slowing down will be in the individual machine itself, and will amount to the slip of the motor, or not more than 2 per cent to 5 per cent.



7-ft. Vertical Resaw Driven by a 75-h.p., 550-volt Slip-ring Induction Motor. Weyerhaeuser Timber Company

A comparison of the operating costs of a large number of steam and electrically driven mills shows that there is a decided reduction in the cost of operation of the latter. This can be accounted for by a reduction in the number of millwrights, oilers, and helpers about the mill; saving in renewals of worn-out bearings, belts, etc.; oil, minimum number of shut-downs due to breakdowns, a constant rate of production throughout the entire mill, and lower insurance rates.

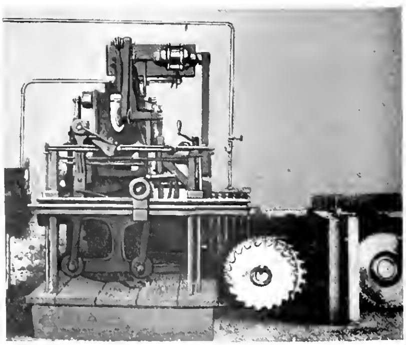
If it is desired to build an addition to the mill, adding new machinery, no long lengths of line shafts, belts, or steam pipes will be required. The change can be made without interfering with the operation of the rest of the mill, and the machinery can be installed just as efficiently and advantageously as that in the original construction.

The induction motor is peculiarly adapted for electric drive in saw mills, as practically all of the different machines run at a constant speed and demand sudden and heavy overloads. For such service there is no electrical machine that will withstand more hard usage than the squirrel cage or wound rotor induction motors.

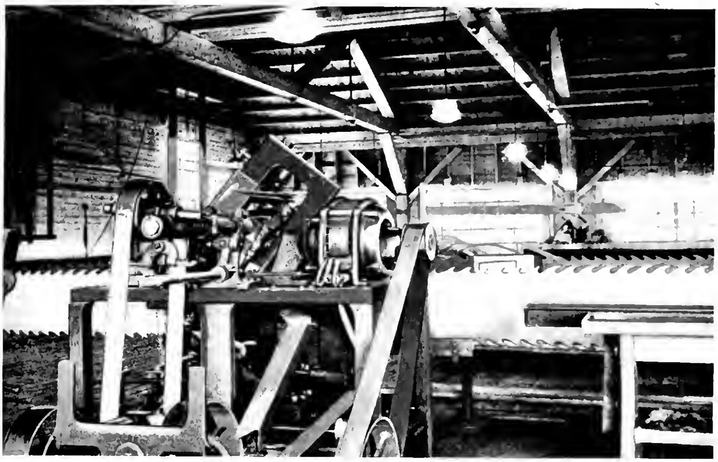
When properly installed with conduit wiring and protective switching apparatus, the danger of coming into contact with live circuits is eliminated. There is no complicated control equipment to contend with, and any motor in the mill can be operated by unskilled labor. The control equipment can be located where it is most accessible for the operator.

Practically the only control apparatus required is the standard compensator for squirrel cage, and oil switches and drum controllers for wound rotor induction motors. Both are equipped with overload and low-voltage protective devices, and have the following additional features:

Safety: All live parts are entirely enclosed



Circular Saw Automatic Grinder Driven by a 3-h.p., 1200-r.p.m., 550-volt Motor. Weyerhaeuser Timber Company



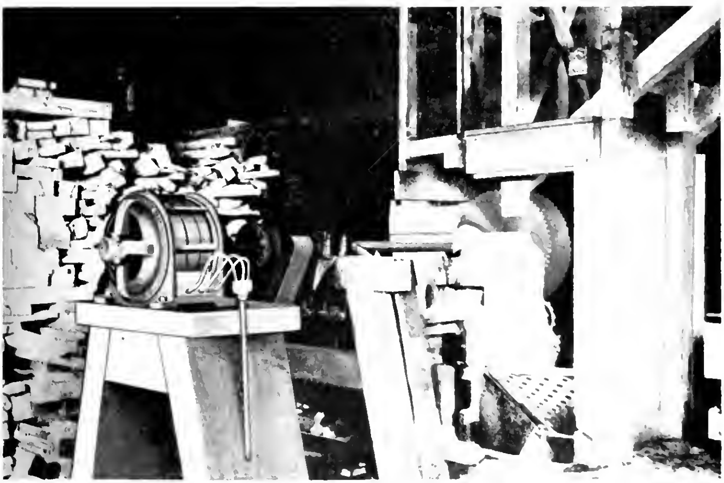
Automatic Grinder, on an 11-in. Band Saw, Driven by a 5-h.p., 1200-r.p.m., 550-volt Induction Motor. Weyerhaeuser Timber Company

RELIABILITY: Excellent electrical and mechanical design not requiring operation by skilled labor.

DURABILITY: Strong construction, insuring long life of all parts.

SIMPLICITY: All parts supported by frame, making installation easy.

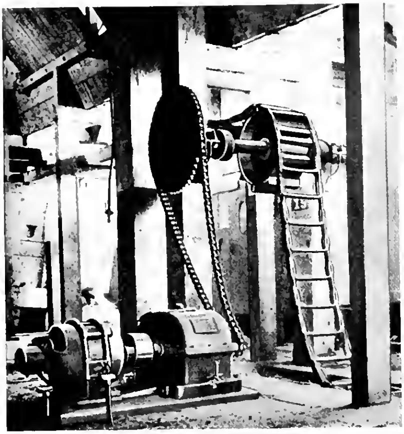
Induction motors constructed with moisture-resisting insulation insure no danger of insulation breakdowns when exposed to moist



Wood Slasher, for Cutting Slabs into 16 in. Lengths, Driven by a 35-h.p., 1200-r.p.m., 550 volt Direct-connected Motor. Weyerhaeuser Timber Company.

salt air or are installed in damp places, as under log decks, timber docks, or other poorly ventilated places.

Owing to the large amount of refuse and waste available, sawmills generally produce their own power, at whatever voltage and frequency give the best results, although three-phase, 60-cycle, 440 or 550 volts is generally used. These voltages have been adopted because the distance of transmission is short and they can be easily insulated. Sixty-cycle frequency allows the use of motors with speeds best adapted for sawmill drive.



Sawdust Conveyor Under 11-ft. Band Saw. Driven by 10-h.p., 1200-r.p.m., 550-volt Motor, Connected through Reduction Gear. Weyerhaeuser Timber Company.

The power requirements of the different machines vary with each individual installation, as this factor depends upon the size, length, and kind of logs, rate of cutting, and the condition of the timber.

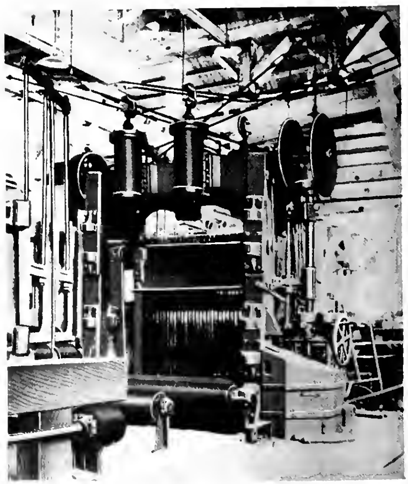
Log Hoists

There are two general methods of transporting logs into a mill. In the more common way the logs are floated on an endless chain. This chain is driven at a speed of 50 to 80 feet per minute by a 35 75 h.p. motor, either belted or direct-connected to the log jack. The motor is of either the squirrel cage type, run continuously, the load being thrown off and on by a friction device, or of the wound rotor type, with resistance to give a high starting torque and control equipment for starting and stopping.

In a number of mills built during the past few years on the Pacific Coast for cutting the large fir and spruce timber, the logs are floated into a pocket built into the mill over cables. One end of the cable is fastened to the edge of the log deck, and the other is wound over a drum which is driven through gear reduction by a belted or geared motor. This motor, with a wound rotor, is rated for intermittent service at from 37 to 52 h.p. capacity, and is provided with a controller for reversing duty and speed control. It is also equipped with a solenoid brake so that the load can be held suspended in case there is not sufficient room on the deck for all of the logs.

Head Saws

One of the largest users of power in a mill is the head saw, whether it is of the circular or band mill type. Although rapidly going out of use, the circular saw is found in many of the older mills and in those in which electric drive has not been installed. The starting



12-in. by 42-in. Gang Saw Driven by a 10-h.p., 550-volt, Slip-ring Induction Motor. Weyerhaeuser Timber Company requirements of circular saws are light, and squirrel cage motors are always recommended. The motors are subject to wide variations in load, the peaks often reaching two or three times the normal demand during a day's cut.

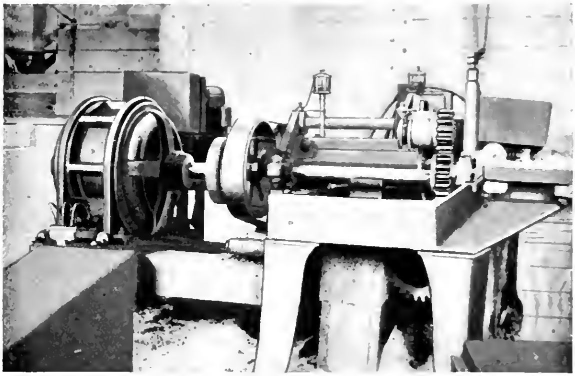
Because the band saw is a much more economical cutter of timber, it is the more desirable type of head saw. The power requirements during the cutting period are not as high as with circular saws under similar conditions, for the reason that the band saw has a heavy flywheel effect which smoothes out the load peaks. The demands at starting, however, are much severer, and wound rotor motors are consequently recommended. Tests on a typical band mill drive indicated a running demand of 300 to 600 h.p. input to the motor. Belted motors are recommended, as this drive permits the use of comparatively high-speed motors.

Carriage Set Works

Motor-driven set works have been successfully installed in several mills built during the past few years. The set works mechanism is driven through a friction disk which is belted to a standard 5-h.p. squirrel cage motor. Power is supplied to the induction motor through a flexible three-conductor cable. As the motor runs continuously no special electrical control is required. The set work control is similar to that used with the steam-driven type, and setters trained to the operation of one can handle the other equally as well.

Live Roll and Chain Transfers

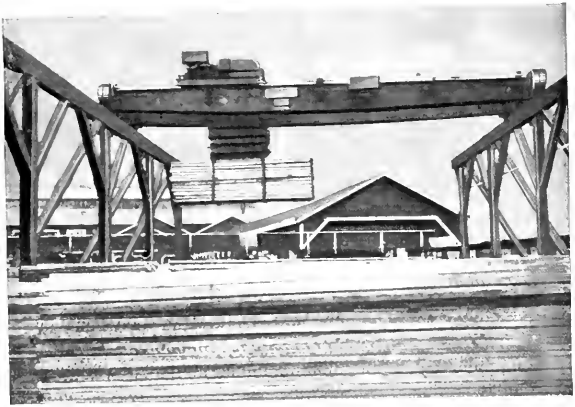
Although only small users of power, the necessity for the continuous running of live rolls and chain transfers is an important factor in production, in that the shut-down of even a single section will prevent the operation of an entire sawing equipment. In some mills several sections of live rolls and other transfers are driven from a common motor, and each section is provided with its individual friction clutch for starting, stopping, and reversing.



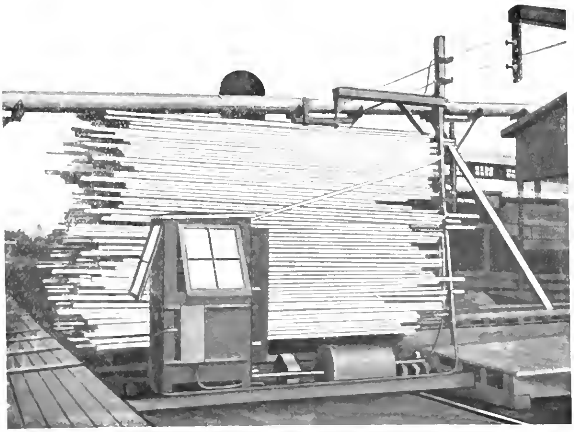
5-Saw Lath Machine Driven by a 35-h.p., 3600 r.p.m., 550-volt Direct-connected Induction Motor. Weyerhaeuser Timber Company

Lath Bolter Driven by a 50-h.p., 1800-r.p.m., 500 volt Direct connected Motor Weyerhaeuser Timber Company

In other mills each section of rolls or chain transfers is driven by individual motors equipped with the necessary control for whatever service is required. Live rolls, which must frequently be reversed, are equipped with high resistance rotor motors which are thrown directly on the line by means of contactors. Push button stations are provided which can be installed in those places that will give the greatest accessibility to the operator. Where frequent reversals are not required and the starting requirements are not particularly severe, standard squirrel cage motors are recommended. In order to secure the low speeds required for this class of service, these motors are back-geared or provided with special gear reductions.



Overhead Crane used in Conveying Lumber from Transfer Cars to Tables in Front of the Planing Machines. Weyerhaeuser Timber Company.



Electrically Driven Transfer Car with Load of Lumber for Dry Kilns.

Conveyors

The power requirements for conveyors are quite similar to those of live rolls, expect that reversing duty of the motor is not required. Where heavy starting duty is imposed, as in burner and long slasher conveyors, motors with wound rotors are generally applied.

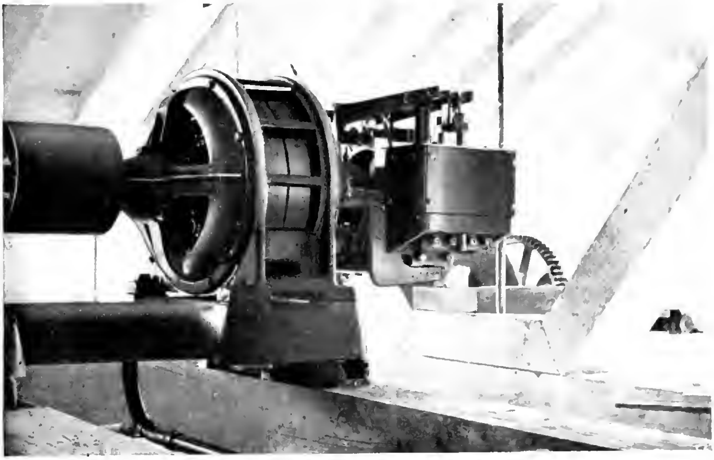
Edgers

Edgers, although large users of power, are readily adapted to electric driver as they require a constant speed with large overload capacity and moderate starting torque, and are arranged for direct connection to the saw arbor. For this service the squirrel cage induction motor is specially suited. The power required by edgers covers a very wide range in the pine mills; motors of 75 to 150 h.p. are usually ample, while those used on the heavy Pacific Coast edgers run up to 300 h.p.

To obtain the speed changes the edger rolls are driven by a 7½- or 10-h.p. squirrel cage motor designed so as to give speeds of 1800/1200/900/600 r.p.m. by changing the number of poles. The control of this motor, consisting of an oil switch and pole changing switch, is mounted where it is readily accessible to the edgerman.

Slashers and Trimmers

Slashers and trimmers, which require a motor of large overload capacity, moderate starting torque, and high speed (for which squirrel cage motors are recommended) are most desirable applications for electric drive. Direct-connected motors are almost universally used, the correct saw speed being

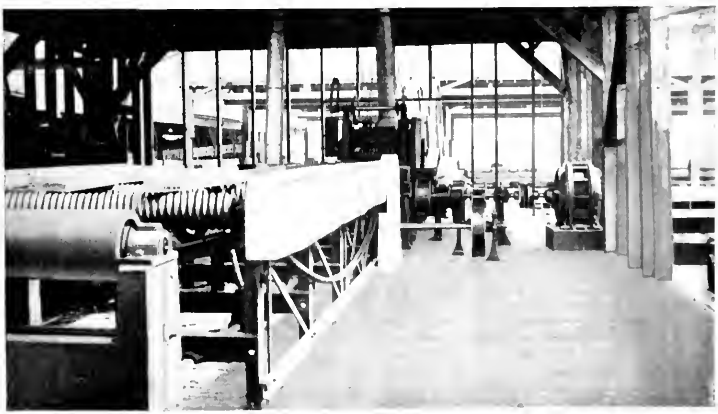


Motor Operating Log Hoist. Booth-Kelly Lumber Company

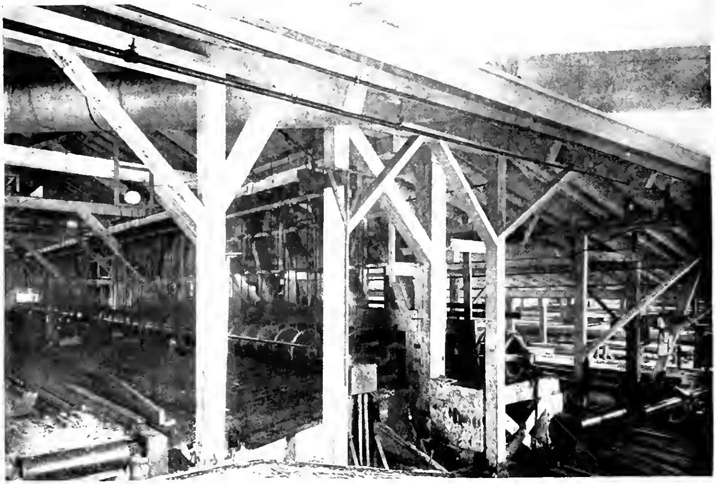
obtained by selecting the proper diameter of saws.

Resaws

In many mills resaws are added either to increase the capacity of the mill or to save lumber by taking another cut from the slabs. The service of the motors driving resaws is identical with that of band mills but on a smaller scale. A seven-foot vertical resaw driven by a 75-h.p. motor mounted on the machinery floor and belted to the band saw pulley is shown on page 154. Close at hand to the operator is located an oil switch and drum



6-in. by 30-in. Double Surfacer Driven by a 75-h.p., 1200-r.p.m. Induction Motor
Booth-Kelly Lumber Company



44-ft Automatic Trimmer and Transmission Machinery for Trimmer, driven by a 50-h.p., 720-r.p.m. Induction Motor. Booth Kelly Lumber Company

10-h.p., 1200 r.p.m., 440-volt Motor Driving the Set Works on the Log Carriage. The Sliding Cable to the Motor is shown along the Right Wall. Booth Kelly Lumber Company controller for changing the speed of a 5-h.p. wound rotor motor which drives the feed rolls through a friction disk.

Gangs

Gangs are installed in many mills to increase production and also to obtain an edge grained product suitable for making flooring. They require from 100- to 300-h.p. motors, depending upon the rate of feed, kind of lumber, etc. The load is more uniform on these than on other types of machines using motors of large capacities. To accelerate the heavy flywheel and saw frame the starting torque of the motor must be large, for which purpose motors with wound rotors are recommended.

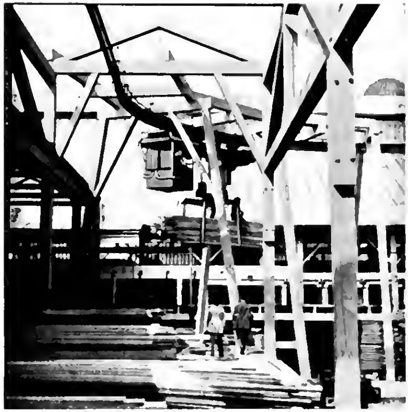
Log Hoist Driven by a 52-h.p., 600-r.p.m., 440-volt Varying Speed Motor. Booth-Kelly Lumber Company.

Lath Mill

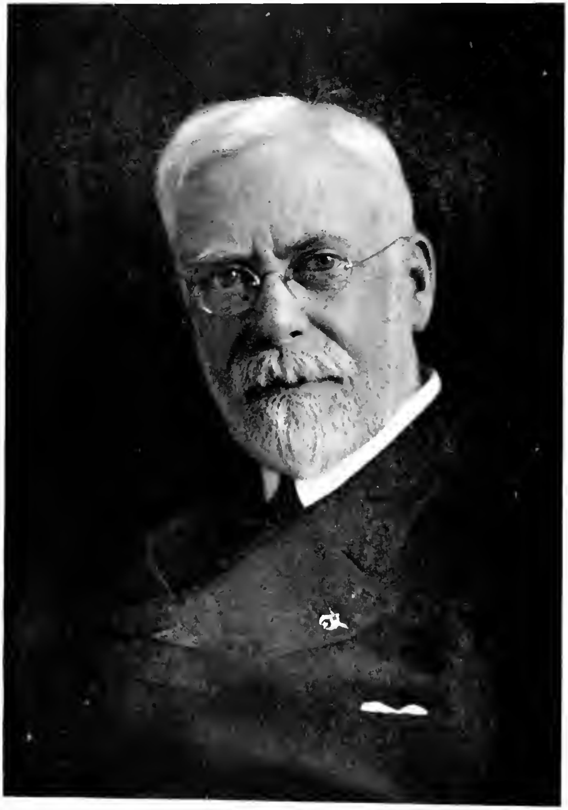
Motor applications to the machines in the lath mill offer no special obstacles in that they all require high-speed direct-connected motors with moderate starting torque, and comparatively large overload capacities.

Transportation

One of the greatest problems in a mill is to have the various operations so arranged that the lumber can be transported from one to the other with maximum speed, minimum loss of time, handling, and distance traveled. Inside the mill this is accomplished by live rolls and chain transfers. Cants to the gang are handled by an electrically operated crane. For service outside the mill storage battery locomotives, motor-driven transfer cars, mono-rail cars, and traveling cranes have been developed, each having its particular advantages for different installations. All of them are successfully driven by electric motors.



Monorail Car Carrying a Package of Lumber to the Dry Kiln Stacker. Booth-Kelly Lumber Company.



JOHN RIDDELL

In Memoriam

JOHN RIDDELL

John Riddell, mechanical superintendent of the Schenectady Works of the General Electric Company, died in Schenectady, December 31, 1917, leaving behind him a host of personal friends and intimate associates in the business world.

Mr. Riddell, born in Ireland in 1852, was conspicuously a self-made man. At the age of 12 or 13 years he started as an apprentice in a jobbing machine shop owned by Nicholas B. Cushing, Jersey City, who made elevators and repaired machinery, especially marine engines. Even as an apprentice his employers selected him to handle some special marine engine repairs because of his remarkable aptitude for work other than routine. The work brought him in contact with marine circles, and he spent the next two years as second engineer on trading steamers plying between the West Indies and Central America and New York.

His first association with the electrical business was with the Daft Electrical Co., where he was rated as a machinist, but was really doing experimental mechanical work, especially in the railway field.

In 1887 he entered the employ of the Thomson-Houston Electric Co., at Lynn, Mass. In 1888 he became foreman of the railway motor shop and was recognized as one of the leading mechanical experts at the time the General Electric Company was formed in 1892.

Mr. Riddell moved to Schenectady in 1895, and shortly after his arrival was appointed Mechanical Superintendent. In this important position he designed special machine tools for increasing the production of the machine shops and also for carrying on the many special processes involved in the manufacture of mechanical tools. Many of these machines were built by the General Electric Company under his direction, and for such tools as were purchased outside, Mr. Riddell not only prepared the specifications, but actually purchased them himself as the Company's trusted representative. He was consulted in regard to all automatic machinery, and his resourceful genius was called in when a solution was sought for difficult mechanical problems that baffled the average expert.

In the sense that Mr. Riddell could obtain large output from machine shops with a minimum cost, he might well be termed a manufacturing economist. He was responsible for the location of machines and machine tools, and his advice and opinion were sought in regard to such manufacturing problems as the routing of the materials from the time the raw product was received until the finished product was ready for shipment.

All the millwrights were under Mr. Riddell's direction, regardless of the fact that he learned his trade in the old school when steam engine and belt drive were supreme. Mr. Riddell was quick to grasp the advantage of individual motor drive for all factory machinery. Having carried on this important work in the General Electric Company's largest factory during the whole period of its development, his knowledge and experience are as great a loss to the General Electric Company as his companionship is personally to those with whom he was associated.

Mr. Riddell had a forceful personality, and in his travels built up a wider acquaintanceship among machine tool manufacturers than anyone else in the Company.

The records of the United States Patent Office show that 37 patents were taken out in the name of John Riddell. There were hundreds of improvements to machine tools which he either invented or regarding which his opinion was sought by manufacturers in various lines. Frequently, designing engineers of machine tool manufacturers have made journeys to Schenectady to show Mr. Riddell a proposed machine tool improvement and obtain his opinion, criticisms, and suggestions.

Among Mr. Riddell's notable achievements in the various works of the General Electric Company is a boring mill—the largest in the world at the time—which was built from his design and which has a sixty-foot swing. This proved so successful for machining large rotors and stators of water-wheel-driven generators that he designed a forty-foot boring mill embodying the same principles for turbine work.

Another of his wonderful machines is the bucket cutter for large steam turbines, which was developed in 1902. It was at this time that the General Electric Company was building the first 5000-kilowatt steam turbine, and this labor- and time-saving device became an important factor in the development of the steam turbine industry at a time when the steam engine was pre-eminent in the largest power plants in the world.

A semi-automatic field coil winding machine was built by Mr. Riddell, and was adopted both in Lynn and Schenectady. It was a labor- and time-saver, and as a single achievement did much to advance the the electrical industry.

Mr. Riddell was awarded a gold medal at the Panama-Pacific International Exposition at San Francisco in 1915, as collaborator in the exhibit of the General Electric Company at the Exposition.

Mr. Riddell was a member of the American Society of Mechanical Engineers, the Engineers' Club of New York, the Society of Engineers of Eastern New York, the Mohawk Club, and the General Electric Quarter Century Club. He belonged to all Masonic bodies in Schenectady, the Oriental Shrine and the Albany Consistory, and was also a member of the Elks.

Those who knew him loved him because of his generous, whole-hearted nature. There were none of those small jealousies in his makeup that are so common to ambitious natures—he was not only willing but anxious to give credit to those who assisted him, and afforded encouragement to those who were striving to improve themselves.

Mr. Riddell is survived by his wife, one daughter, and two sisters.

Temperature Sensitive Paints

By W. S. Andrews

Consulting Engineering Department, General Electric Company

The above term has been applied to chemical compounds that are subject to color changes at a comparatively small rise in temperature. These paints are occasionally used for indicating a dangerous rise in the temperature of machine bearings, electric generators and other apparatus where excessive heating has to be avoided.

The two compounds described below are easy to make and reliable in operation.

The Double Iodide of Mercury and Copper

This compound is normally red but turns black at about 87 deg. C, becoming red again when the temperature falls.

Preparation

Make separate solutions of copper sulphate and potassium iodide in distilled water. Add the latter to the former with constant stirring until the precipitate which is first formed is re-dissolved. Then add a strong solution of mercuric chloride (corrosive sublimate) and the red double iodide of mercury and copper will be precipitated. Wash and dry this precipitate on filter paper. The red powder may be mixed with a weak solution of gum arabic in water and used as a paint.

The Double Iodide of Mercury and Silver

This compound is normally of a light primrose yellow, but turns to a dark orange or brick red at about 45 deg. C. It becomes yellow again on cooling—and it may be heated and cooled an unlimited number of times without losing its curious property, providing it is not overheated.

Preparation

Make separate solutions of silver nitrate and potassium iodide in distilled water. Add the latter to the former with constant stirring until the original precipitate is dissolved. Then add a strong solution of mercuric chloride (corrosive sublimate) which will produce a precipitate of the double iodide of mercury and silver of a bright yellow color. Wash and dry the precipitate on filter paper. It can be used as a paint by mixing with a weak solution of gum arabic in water.

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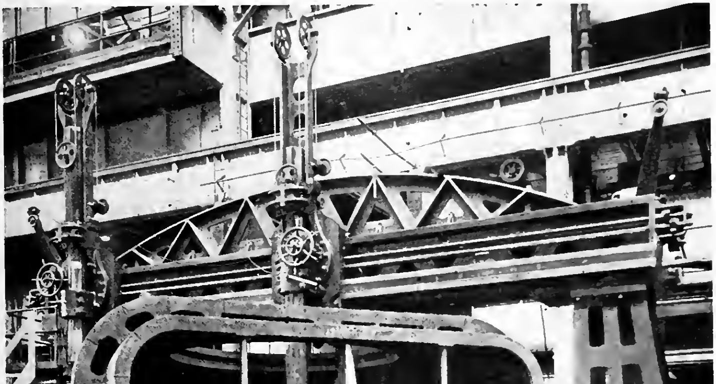

EXHAUST SHELL OF A 45,000-KW. CURTIS TURBINE ON A 40-FT BORING MILL. THE FUEL SITUATION DIRECTS ATTENTION TO THE EFFICIENCY OF THE MODERN TURBINE WITH HIGH STEAM PRESSURE AND SUPERHEAT. (See page 216

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For a description of beet-sugar production see page 188

GENERAL ELECTRIC REVIEW

OUR WAR PROGRAM AND THE VALUE OF CO-OPERATION*

By E. W. Rice, Jr.

President American Institute Electrical Engineers

There never was a time in the history of the world when work was more needed, and talking only justified when it will help forward the great work which is at hand. We all know what that great job is—the winning of the war. Everything else must take a back seat and wait until that job is done. I would much rather now try to do my bit of work to aid this great cause than to talk about it, but as you have asked me to talk to you, and as I can think of nothing more important to talk about, I trust that you will be patient if I talk to you a little about the war.

I wish first to say that we are fortunate in having in our President a spokesman who is able to state the ideals of the American people and their purpose in this great war in a manner so clear and so impressive as to perfectly satisfy and thrill every loyal American, and he has so appealed to our Allies that he is now accepted as the leading spokesman for all on our side of the war. If our enemies were in a position to listen to an "appeal to reason" we could even hope that his messages would be accepted as the basis of peace. It is fortunate for the world's future that his messages contain no indication that we will be satisfied with an inconclusive peace, and no matter how much we may hope that his messages may eventually break down the resistance of our enemy, through an appeal to reason, we are warned that it is vitally necessary to throw our full strength into winning the war, through the exertion of superior military and naval, and industrial power.

I suppose we all think we know just how to win this war, and we are all ready to give advice in private and some even in public. The newspapers, Congress, a long list of voluntary associations, engineering councils, labor leaders, business men, chambers of commerce, are all offering their advice to the administration.

The average citizen is mystified and wonders just what is the matter; he has been told that the greatest possible production, especially of war material, was vital to our success, and this appealed to his common sense; but just as our manufacturers were getting up speed and working at high pressure they have been ordered to stop and to reduce pressure, as production is said to be ahead of the distributive facilities of the country. He has been told that the army organization had completely broken down; he has seen reports that the submarine menace had been mastered, only to note that the sinkings continue at an alarming rate; he was told that millions of tons of shipping were needed, and an organization was started to build these ships; he saw months of time wasted in talk at a time when every day lost meant the loss of millions of dollars and thousands of lives. After months of weary waiting the dead-lock was broken and we got fairly launched upon a shipping program. We thought that we were running along fairly well when suddenly the entire country was stunned by the recent drastic order of the Fuel Administrator, closing many industries, and stopping much of business life.

We were all greatly encouraged and thrilled during the early months of the war by the patriotic attitude of Congress which supported the administration in an unprecedented manner, without distinction of party.

The two great Liberty Loans aggregating between five and six billion dollars were voted and raised with the patriotic and enthusiastic support of all the country, and we are told that when history has been

* Postprandial Address, Sixth Midwinter Convention, A.I.E.E., New York City, February 15, 1918.

written naughty Wall Street will deserve a decoration for its patriotic and efficient assistance. A great scheme of taxation, more drastic and bearing more heavily upon the wealth of the country than anything known in our history, has been passed and will be loyally supported even by those who are most heavily hit.

The selective draft system was prepared and put into operation and accepted by the country in a truly magnificent manner. The Red Cross has been reorganized and an enormous amount raised by voluntary subscriptions, and is well started on its beneficent and valuable mission. The Knights of Columbus are also doing magnificent work in a similar field. I will not take your time to sketch further the tremendous activities which this country has started during the past year.

In view of this record of accomplishment, and our truly splendid start in the war, why has this feeling of nervousness come over the country? Why has Congress suddenly changed its attitude of unquestioning support to one of investigation and criticism? What does it all mean? Is it true that we are making a failure of the job?

It seems clear to me that we have not made a failure and that everything is moving along as well as we had a right to expect under all the circumstances. When we consider that less than a year ago our nation of a hundred million of people, entirely unprepared for war, with institutions and traditions only adapted to the conditions of profound peace, was thrust into this greatest of enterprises, it is clear that we have already accomplished wonders and that we should not be discouraged. In spite of eminent authority, a million men cannot spring to arms overnight, nor can dreadnaughts, destroyers, submarines, antisubmarine devices, heavy ordnance, and all the great mechanism of war, be produced in a day, in a month, or even in a year, no matter how much we pray or "cuss" or work. A certain minimum of time is necessary to start, equip, and get this nation into the war effectively. We should do everything possible to see that this minimum of time is not unduly prolonged. Business men, and especially engineers and manufacturers who understand the nature of the equipment required for this conflict, however, must appreciate that our fundamental, and let us hope not fatal, mistake is that we waited until the war was thrust upon us before we started to get ready.

I think a little reflection will make it clear that the mistakes which we have made since we started in the war, however numerous or avoidable, are in the aggregate negligible compared with the overwhelming mistake of failure to prepare for the war during 1915 and 1916. That precious time has been lost forever and no effort or time, criticism or talk can cancel that mistake and give us back the lost time. We must expend untold billions, and we must make superhuman efforts, but we must be patient and realize that inconsiderate haste is likely to result in added friction, lost motion, false starts, and a general retardation of our program.

While it would seem that, considering our history and our type of Government, with its checks and balances, we have done fairly well since we started in the war, we realize that we have fallen short of what we would like to have accomplished, and we should not be satisfied, and constructive criticism should not be discouraged. I believe, however, that we should not become unduly disturbed, but rather be encouraged at the prospect. "While there is life there is hope," and the very fact that the country has energy enough to kick violently while it is working, clearly demonstrates that there is no possibility of dissolution or thought of defeat.

Now what kind of constructive suggestions can we offer, may I inquire? I hesitate to make any suggestions. However, as a business man and engineer there are certain matters which seem to me worthy of consideration.

I start with the premise that this is a peoples' war—a war for democracy. To be successful the people must believe in the war and must work for the war. It would seem, therefore, that this fact being recognized we should not attempt to handle the job on the basis that it is to be run exclusively by the party in power. In such an emergency it does not seem probable that we can get best results by our customary majority or party government. All the people must be represented. The party in power represents at best only a bare majority of the people, and to win a peoples' war all the peoples' representatives should be given an opportunity to share the responsibility.

It seems quite probable that the questioning attitude of the country today is due more than anything else to a growing fear that the full ability, wisdom, and experience of the country is not being properly utilized.

When at war every important force in our nation must be enlisted to the fullest extent and in the most efficient manner. The support of the country has been magnificent. Would not this confidence be greatly strengthened if those in political control would look beyond their party, and take into the service of the nation its strongest men without reference to political affiliation?

There are plenty of such men who are willing to help the country, and the country wants them put to work worthy of their records and abilities, not under dictation but as partners of our great enterprise. England has met the situation by a so-called Coalition Government. Why can't we do something similar?

The country is greatly encouraged at the large number of able men, prominent in business and other walks of life, who have volunteered for service in various departments of the Government and who have been accepted and set to work. This policy should be encouraged, as the more it is followed, the better the country will be satisfied, and the sooner we shall win the war.

It is essential that the men who are charged with enormous responsibilities in our Governmental enterprises have the confidence of the country, as their orders, no matter how drastic or arbitrary or apparently unnecessary, should be followed with confidence. At the present time orders are patriotically obeyed, but with some misgiving, due not so much to the hardships inflicted as to the feeling that our leaders do not fully realize what they are doing. There is no lack of confidence in their good intentions and character, but there is some questioning of their wisdom and practical experience.

After all, in my opinion, the question of the exact form of any organization is relatively unimportant. The effectiveness and value of any organization is largely dependent upon the men who are on the job. The theoretically perfect system would break down and prove an utter failure if administered by men who are arbitrary, inexperienced, or lacking in the spirit of co-operation. On the other hand, a system that is apparently defective on paper can be made to operate with the greatest measure of practical success if the men filling positions of power and responsibility are men of vision, wisdom, practical experience, and full of the spirit of co-operation, men who take to "team-play" as naturally as a duck takes to water.

We are now making a vigorous effort to adjust ourselves to the work of winning the great war into which we have been thrust. We are all on trial. If our institutions and methods are found to be such that they cannot function properly and efficiently under war conditions, we shall have to modify them to whatever extent may be necessary.

Every organization must demonstrate what it can do to help the country in its hour of need. Every organization, whether of capital, labor, manufacture, or business, and every individual must be subjected to the test of whether it is doing its best and most effective work to win the war. This will be the only and supreme test. Every individual who fails to put forth the maximum effort in the most efficient manner must be brought into line.

It is obvious that no single element by itself can win the war. Capital alone is helpless; labor alone is equally helpless. The Navy cannot win without the help of the Army, and both are helpless without ships. The sacrifices cannot be made by capital alone, or by labor alone, but must be distributed on a fair basis.

The test of patriotism will be the willingness to work, each in his own sphere, to the absolute limit. We need the maximum output of brains, labor, and material; the country demands it, and the country will see that it is obtained. Any man or organization of men that stands in the way of the purpose which this country has set for itself will be eventually crushed.

I don't suppose that we can form any adequate idea of the stupendous task which the Government has undertaken, in its army, navy, shipbuilding, aircraft, and other programs. It simply staggers the imagination.

The personnel of the Governmental organization has undergone a rapid and tremendous expansion. The organization which was sufficient for our small peace program was, of course, absolutely unable to cope with the war program. It is manifestly impossible to build up a new organization which will operate satisfactorily at once. It has taken many years to build and perfect the great industrial organizations of our country. The transfer of a man to Government service does not change his character or necessarily increase his efficiency. After any organization has been brought into existence, time is required for the different units to learn their duties and particularly to learn how to co-operate with each other.

Time is also required for the country to transfer its industrial activities from commercial work to Governmental work. While this transfer must be made as rapidly as possible, even if great loss ensues, there is a limit to the rapidity with which this transfer can be effectively made, and if we exceed that limit, we will introduce so much waste and friction that the rate of transfer will be reduced and our object of increased producion for the Government temporarily defeated.

It takes time for us to get over our ideas and practices, based upon our competitive conditions and education. We are now to forget our education in competition, and think of nothing but co-operation; in other words, of what is best to increase the country's production as a whole, for that is vital in winning the war.

It is obvious that the Navy and Army cannot be built up without drawing upon the organization and facilities of the country, and that their activities cannot be maintained without an efficient industrial organization constantly at work behind them in this country. Therefore our Government, as well as ourselves, must never forget that the preservation of the country's industries in the highest state of efficiency is a vital matter.

In order to avoid chaos, it is essential that Governmental departments should co-operate with each other, and such co-operation is not merely a matter of organization but largely a matter of men or personnel. Some men cannot co-operate. Such men are not useless, but they cannot be used in administrative positions. A man at the head of an important Governmental office or department must co-operate with the heads of other departments and must arrange to have such co-operation extend to each and every person under his control. Co-operation to be effective must be wholehearted and instinctive.

I like the President's expression, "Spirit of accommodation," for that is the essential element of co-operation.

Now I wish to emphasize the fact that it takes time to produce really efficient co-operation. No new organization can possibly work as smoothly and effectively as one which has had time to become perfected.

Moreover, co-operation in Washington between departments will not entirely settle the matter. We have a duty to perform. There must be co-operation among the industries. We must forget to compete and learn to co-operate with other units.

But this is not all: we must have co-operation between the Government and industries, and, to be effective, this means that both must be a party to the co-operation. It cannot be a "lion and lamb" sort of affair. If the Governmental heads use their vast power arbitrarily and unwisely, they can easily cripple the industries of the country, and thus delay victory for years.

Take for example the matter of priority. This is merely one of the factors of production. All large industrial establishments handle such matters through a production department with a production manager at its head. Such a man is settling questions of priority every day. If he settles them wisely, the industrial organization is successful; if he makes many mistakes, the organization will function badly and probably fail. If an inexperienced man were put in charge of the production of any establishment, he could, and probably would, with the best of intentions, reduce the productive efficiency of such an establishment by 50 per cent within a few weeks.

In many of the big industrial organizations which have grown up during the past twenty-five years in the United States, will be found excellent examples of co-operation. No man can be successful in an administrative position, large or small, in such an organization, who does not understand and practice co-operation as second nature; in fact, such organizations found that co-operation was so much more efficient and economical than destructive competition that they began to co-operate with other competing units, but were prevented by law.

The country has now found that these organizations are extremely useful under the present conditions, and also that they are composed of individuals who have been trained in loyalty, and who are devoting themselves loyally and enthusiastically to the service of the country. Such service is rendered not only by individuals enlisting in the Government work, in the Army, Navy, and elsewhere, but frequently, and even with greater effectiveness, by remaining with their organization and turning its facilities, as rapidly and to the extent that is practical, over to work for the Government. The value of the service of such organizations to the Government and the country is greater than the aggregate value of the individuals or the material facilities of the organization, because the value of each and every part of an efficient and live organism is multiplied by the very fact that it is part of an organism trained to "team-play." Care must be taken not to disintegrate such organizations, as otherwise great value will be lost to the country at this critical time.

I believe that the problems facing us will be successfully solved in time, but we need more co-operation, more of the spirit of accommodation, all our patience and wisdom, and, above all, a willingness to work to the limit.

We must discipline ourselves until a shirker in any field of useful effort will be regarded with the same contempt as a shirker in the military service of the country. There is no difference, or if there is any difference, a shirker behind the lines is worse than one in the trenches.

Railway Electrification as a Means of Saving Fuel and Relieving Freight Congestion*

By E. W. Rice, Jr.

President American Institute Electrical Engineers

A recent estimate of the horse power of steam railway locomotives in the United States places the figure at 25,000,000. This compares with an estimate of 8,500,000 horse power for all of our central stations and an additional 4,500,000 horse power for isolated plants. Mr. Rice states that these locomotives consume annually 150,000,000 tons of coal, two-thirds of which could be saved by electrification. There is no guess work about this statement, as its truth has been demonstrated in actual operation. Under average conditions the steam locomotive requires six pounds of coal per horse-power hour, while present central stations could move the same trains with a consumption of only two pounds of coal per horse-power hour. This saving in fuel is only one of the great advantages that Mr. Rice points out would result from electrification of our railways.

—Editor.

Members of the electrical profession and industry have reason to be pleased with the contributions which they have made for the benefit of the world. While we are glad to think that our science and our industry are fundamentally devoted to the products and conditions of peace, we realize that in the electric light, searchlights, the X-ray, telephones, telegraph, wireless apparatus, electric motors, etc., electricity plays an important part in the grim business of war.

We are in the midst of an extraordinary coal famine, due to causes which it is perhaps undesirable for us to attempt to outline. However, I would like to point out how much worse the situation might have been were it not for the contributions of the electrical engineer; and also how much better our condition might have been if our contributions had been more extensively utilized.

Suppose we assume that the present serious situation is due to a lack of production of coal. It is comforting to consider to what extent conditions surrounding such production have been improved and how the output of our coal mines has been already increased by the use of electrical devices in connection with coal mining—such for example, as the electric light, electric coal cutters, electric drills, and electric mining and hauling locomotives. I have no figures before me, but I think it is a fair assumption that the output of coal mines should have been increased at least 25 per cent on the average by the employment of such electrical devices. If this estimate were cut down to 10 per cent it would still leave a possible increase in the tonnage of coal produced of something like 50,000,000 tons during the past year.

If, on the other hand, our situation is not due to a shortage in the production of coal, but rather to the failure of the distributive agencies of the country, which is more probable, it is interesting to see how this difficulty would have been largely removed if the railroads of the country were operated by electricity instead of steam.

Where electricity has been substituted for steam in the operation of railroads, fully 50 per cent increase in available capacity of existing tracks and other facilities has been demonstrated. This increased capacity has been due to a variety of causes, but largely to the increased reliability and capacity, under all conditions of service, of electric locomotives, thus permitting a speeding up of train schedules by some 25 per cent under average conditions. Of course, under the paralyzing conditions which prevail in extremely cold weather, when the steam

* Presidential address at the Sixth Midwinter Convention of the A.I.E.E., New York City, February 15, 1918.

Trans-continental Passenger Train "Olympian" Climbing the Rockies before Electrification

All-steel Passenger Train "Olympian" at Deer Lodge after Electrification locomotives practically go out of business, the electric locomotives make an even better showing. It is well known that extreme cold (aside from the physical condition of the traffic rail) does not hinder the operation of the electric locomotive but actually increases its hauling capacity. At a time when the steam locomotive is using up all its energy by radiation from its boiler and engine into the atmosphere, with the result that practically no useful power is available to move the train, the electric locomotive is operating under its most efficient conditions and may even work at a greater load than in warm weather. It may, therefore, be said that cold weather offers no terrors to an electrified road, but, on the contrary, it is a stimulant to better performance instead of a cause of prostration and paralysis.

But this is not all. It is estimated that something like 150,000,000 tons of coal were consumed by the railroads in the year 1917. Now we know from the results obtained from such electrical operation of railroads as we already have in this country that it would be possible to save at least two-thirds of this coal if electric locomotives were substituted for the present steam locomotives. On this basis there would be a saving of over 100,000,000 tons of coal in one year.

This is an amount three times as large as the total coal exported from the United States during 1917.

The carrying capacity of our steam roads is also seriously restricted by the movement of coal required for haulage of the trains themselves. It is estimated that fully 10 per cent of the total ton mileage movement behind the engine drawbar is made up of company coal and coal cars, including in this connection the steam engine tender and its contents. In other words, the useful or revenue carrying capacity of our steam roads could be increased about 10 per cent with existing track facilities by eliminating the entire company coal movement.

I have not mentioned the consumption of oil by the railroads which we are told amounted in 1915 to something like 40,000,000 barrels, nearly 15 per cent of the total oil produced. This fuel is entirely too valuable to be used in a wasteful manner. It is important for many reasons that such a wonderful fuel as oil should be most economically used, if for no other reason than that it will be needed for the ships of our forthcoming merchant marine, for the tractors that till our fields, and the motor trucks that serve as feeders to our railways.

The possible use of water power should also be considered in this connection. It is estimated that there is not less than 25,000,000 h.p. of water power available in the United States, and if this were developed and could be used in driving our railroads, each horse power so used would save at least 6 lbs. of coal per horse power hour now burned under the boilers of our steam locomotives. It is true that this water power is not uniformly distributed in the districts where the railroad requirements are greatest but the possibilities indicated by the figures are so impressive as to justify careful examination as to the extent to which water power could be so employed and the amount of coal which could be saved by its use. There is no doubt that a very considerable portion of the coal now wastefully used by the railroads could be released to the great and lasting advantage of the country.

The terrors of these "heatless days" will not have been without benefit if they direct the attention of the people and of our law makers to the frightful waste of two of our country's most valuable assets—our potential water power and our wonderful coal reserves. The first, potential water power, is being largely lost because most of it is allowed to run to waste, undeveloped, unused. The second asset, coal, is wasted for exactly the opposite reason. It is being used but in an extravagant and inefficient manner.

Our waterfalls constitute potential wealth which can only be truly conserved by development and use—millions of horse power are running to waste every day, which once harnessed for the benefit of mankind become a perpetual source of wealth and prosperity.

While the amount of coal in our country is enormous, it is definitely limited. While Providence has blessed us with a princely amount of potential riches in our coal beds, it is known that there is a finite limit to the amount of coal so stored and when this coal is once exhausted, it is gone forever. It is really terrifying to realize that 25 per cent of the total amount of coal which we are digging from the earth each year is burned to operate our railroads under such inefficient conditions that an average of at least six pounds of coal is required per horse power hour of work performed.

The same amount of coal burned in a modern central power station would produce an equivalent of three times that amount of power in the motors of an electric locomotive, even including all the losses of generation and transmission from the source of power to the locomotive. Where water power may be utilized, as in our mountainous districts in the West, all of the coal used for steam locomotives can be saved. In the middle and eastern states, however, water powers are not sufficient and it will be necessary in a universal scheme of electrification that the locomotives be operated from steam turbine stations but, as I have already stated, the operation of the electrified railroads from steam turbine stations will result in the saving of two-thirds of the coal now employed for equivalent tonnage movement by steam locomotives.

It is, therefore, not too much to say that if the roads of the country were now electrified that no breakdown of our coal supply, due to failure of distribution, would exist. What this would mean for the comfort of the people and the vigorous prosecution of the war, I will leave for you to imagine.

Of course, this picture which I have briefly and inadequately sketched of the great benefits which our country would have received if the roads had been electrified does not improve our present situation, and it may be claimed that any discussion of such a subject at this time is of an academic nature. This point of view is in a sense true, but I think that we can properly take time to consider it because of the effect which it may have upon our future efforts. This picture is not merely an inventor's dream but is based upon the solid foundation of actual achievement. We have had enough experience upon which to base a fairly accurate determination of the stupendous advantages and savings which will surely follow the general electrification of the railroads; in fact, I think we can demonstrate that there is no other way known to us by which the railroads problem facing the country can be as quickly and as cheaply solved as by electrification.

The solution of the railroad problem would also "kill two birds with one stone" by solving the fuel problem at the same time.

If it is a fact, as has been stated, that the steam railroads of the country have failed to keep pace with the country's productive capacity—the increased output of manufacturing industries, the extension of agriculture and other demands for transportation it is obvious that if the country is to go ahead, the railroad transportation problem must be solved and it must be solved at the earliest possible date. It becomes a matter of national importance that the best solution should be reached in the shortest possible time. That solution is best which will give the greatest amount of transportation over existing tracks, in the most reliable manner, and if possible, at the lowest operating cost. We electrical engineers are confident that we can make good our claim that the best solution is to be found in a general electrification of the railroads. That such a solution would be of great advantage to our profession and to our industry is important, although not as important as the great advantage which it would be to our country, freeing it as it would from the present threatened paralysis of business, possibility of untold human suffering and incalculable financial loss. It should give us courage and optimism for the future of our profession to contemplate the service which we may render in this direction, and which it seems to me is immediately at hand. It should arouse in all of us, and particularly in the younger engineers, an enthusiastic confidence in the present and future stability and value of our profession and of the electrical industry. It should satisfy the young engineer that the opportunity for him to render important service is as real and great today as it has been in the past for those of us who have seen and participated in the marvelous growth of the industry up to the present time.

We would not be justified in being so confident of the benefits of electrification of railroads if every element in the problem had not been solved in a thoroughly practical manner. The electric generating power stations, operated either by water or by steam turbines, have reached the highest degree of perfection, efficiency, and reliability, while the transmission of electricity over long distances, with reliability, has become a commonplace. Electric locomotives capable of hauling the heaviest trains at the highest speeds, up and down the heaviest grades, have been built and found in practical operation to meet every requirement of an exacting service. There is, therefore, no element of uncertainty, nothing experimental or problematical, which should cause us to hesitate in pressing our claims upon the attention of the country. Electrification of railroads has progressed with relative slowness during these many years, waiting upon the development and perfection of all of the processes of generation and transmission and of the perfection of the electric locomotive itself. When all these elements had been perfected, as they now have been for several years, the railroads found themselves without the necessary capital to make the investment.

I realize that the task of electrifying all of the steam railroads of the country is one of tremendous proportions. It would require under the best of conditions many years to complete and demand the expenditure of billions of dollars.

The country, however, has clearly outgrown its railway facilities and it would require, in any event, the expenditure of billions of dollars and many years of time to bring the transportation facilities up to the country's requirements.

It is not necessary that electrification should be universal in order to obtain much of its benefits. It is probable that the most serious limitations of our transportation system, at least in so far as the supply of coal is concerned, is to be found in the mountainous districts and it is precisely in such situations that electrifications has demonstrated its greatest value. Electrification of a railroad in a mountainous district will, in the worst cases, enable double the amount of traffic to be moved over existing tracks and grades.

If a general scheme of electrification were decided upon, the natural procedure would be, therefore, to electrify those portions of the steam railroads which will show the greatest results and give the greatest relief from existing conjestion. Electrification of such sections of the steam railroads would have an immediate and beneficial effect upon the entire transportation system of the country and it is our belief that electrification offers the quickest, best, and most efficient solution that is to be obtained.

It may be said that the present is not a propitious time in which to deflect any of the country's money into railroad electrification. I think that in spite of the enormous advantages of which I have spoken, we would be inclined to agree with such a point of view if it were not for the recent unpleasant demonstration of the failure of our railroad transportation systems to meet the demands which have been placed upon them by the industries, aggravated, it is true, by the war conditions and also by the unkindness of the weather.

After all, the question for the country to decide is whether we dare to limp along with the present conditions of restricted production, due to limited transportation, at a time when the world demands and expects from us the greatest possible increase in our efficiency and total production.

What assurance have we that the present conditions are temporary, and even if they improve as they surely shall with the coming of warm weather, what are we going to do next winter? Of course, even if we should start electrification at once, we could not have all our railroads electrified by next winter but we could have a good start, and as Sherman said about the resumption of specie payments, "The way to resume is to resume," so "The way to electrify is to electrify."

Standardized Flexible Distributing Systems in Industrial Plants*

PART I

By Bassett Jones

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The author has worked out a system for determining the power requirements of industrial plants in advance of construction, the method being based on a relationship between projected tool area, manufacturing area, and total square feet of floor area. The study of this subject was undertaken in connection with the electrical distribution for a new factory building of the Sprague Electric Works, General Electric Company, and its application to this building will be described in our April issue. We have standardized practically all equipment employed in the generation and distribution of electric power, except distribution systems in industrial buildings, and the author shows that standardization here is equally practicable and desirable. In any industrial plant flexibility in distribution to take care of frequent changes in machine tool layout is of the utmost importance, and the author has given this matter special consideration.—Editor.

Introduction

Within the last few years the design and application of devices and equipment for generating and utilizing energy in industrial plants has made great strides forward. Much has been written and said about generators, motor drive and methods of control, and about illumination. Little effort, however, has been made to improve upon the method of bringing energy to the devices where it is to be used.

The reason for this is clear. The manufacturer of the devices referred to is naturally interested in their improvement and use. Competition forces him to study constantly the characteristics of the apparatus he makes and to analyze carefully its application, to the end that he may improve it and so outdistance his competitor. For this purpose the manufacturer maintains a highly trained and expensive corps of engineers and even great research laboratories, the sole function of which is the study and development of methods for economically generating and utilizing energy.

Sometimes the design of the distributing system has a vital bearing on the successful use of the manufacturer's devices, and then he is interested enough to furnish data for, or assist in, the proper design of the system. Such, for instance, is the case in the construction of high tension distributing systems where seemingly slight errors or omissions in the design may produce operating conditions that will cause serious failure of the parts of the system in which the manufacturer is interested. However, it is not the purpose of this paper to discuss high tension equipment, but only that equipment which applies direct to manufacturing processes where low pressures are used.

In most cases the manufacturer does not install the distributing system. He is not responsible for its successful operation and is not, therefore, vitally interested in its design, except in so far as he is interested in the manufacture and sale of its component parts. Here, however, if these parts function correctly, the manufacturer's interest practically ceases with their delivery to the customer. It is up to the customer to use them properly. The design of the distributing system is, therefore, frequently left to some employee of the purchaser with the help of what little "dope" he can gather from the motor salesman and somebody's handbook, or it may be left to some electrical contractor to connect up the tools and lights. Occasionally an experienced engineer is employed to study the needs of the situation and prepare proper plans for the work.

Another reason why the manufacturer of electrical devices is not interested in the distributing system except in selling its parts, is due to the fact that the distributing system is inherently a variable, to be designed for each installation. It is essentially a made-to-order product and therefore has been assumed to be impossible of standardization. It will at once occur to us that the manufacturer has standardized practically everything that goes into the distributing system—switchboards, panel boards, switches, cutouts, conduits, wire and cable, sockets, reflectors, and innumerable fittings of every description, all or some of which may be assembled or fitted together in one way or another to meet a great variety of conditions.

This is quite true: yet is it not possible that a system might be devised in which a fewer number of parts or fewer sizes of these parts might be necessary, and in which standard assembly groups could be used? For instance, there are almost as many different kinds and

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arrangements of panel boards in all the modern buildings in existence as there are centers of lighting circuit distribution. Is there not some way of designing the lighting system so that a few, or even one size and type of panel, can be made to meet many conditions?

Again, consider the switchboard. In the last few years a decided step in the right direction has been made in standardizing switchboard panels. So far so good. It has probably vastly increased output for a given overhead, simplified merchandizing, and increased dividends. But why stop here? Look over the catalogues of standard switchboard panels—a volume at the very least. Is it not again possible to devise a distributing system that will require, at the most, but a few such panels, or perhaps, a few standard frames and a few standard parts that can be fitted into the frames so as to produce a large number of combinations—combinations that, if necessary, can be changed at various times after installation to suit changes in the distributing system? As you know, such changes are frequent and often radical. In fact, this grouping of standard parts to meet special conditions is one of the most important things we have to consider.

We might go on in this vein indefinitely, but here we have mentioned the whole crux of the problem—variations in and remodeling of the distributing system brought about by constant changes in factory arrangements and manufacturing processes. Perhaps in studying the system from this point of view we may approach a solution of our other problem in which the manufacturer of electrical apparatus is particularly interested. But before apparatus or assembly groups can be standardized the distributing system must be standardized.

The form of our proposed standard distributing system must necessarily adapt itself to building conditions; this must always be kept in mind. It must be possible to install the system in any ordinary form of building built in any ordinary way out of any ordinary materials—wood, mill construction, brick, and steel or reinforced concrete, or any combination thereof; and whether the building be one story with flat, peaked, monitor or saw-toothed roof, or ten stories in height; high ceilings or low, flat or with projecting beams; in plan, square, rectangular, L or H, or any other form of any dimensions; one bay or three bays wide. The system must be contrived so as to go easily into any such building at as low a first cost as may be, provided only that it is possible to rearrange the system at any time without shut-down and at comparatively small expense. You will probably agree that any distributing system that will fulfill the last requirement alone—that can be easily and cheaply rearranged without shut-down—would be worth its salt and would probably warrant some initial extra outlay.

The bane of the factory wiring system has been the "extra." Was there ever a factory wired from the original plan without any changes? This amounts to the same thing as asking whether the tool layout in any factory was ever determined once for all before the building was wired, and thereafter never changed? We all know that no such thing exists as a fixed factory plan inside the outer walls. I wonder if you know how much it costs each year to rewire the buildings with which you are familiar? Not only the cost of the changes in the wiring system but also all the cutting and patching that go with it. I have been laughed at for asking so foolish a question. Yet I have seen twenty to thirty feet of flooring ripped up to wire to one additional tool. One tool! and I believe that a tool plan in any live, growing, moving factory or even department made this year would hardly be recognizable next year.

Here is a group of screw machines that next year must all be moved to make room for additional machines. Two years from now these tools will be torn out and a less number of a new and different kind installed; or it is found that if these machines are moved to another location some lost motion in manufacture is saved, and cost of manufacture is reduced a mill per stud or a penny a part amounting to some thousands of dollars a year in production. And so it goes.

Within the limits of a single paper it is, of course, quite impossible to discuss the design of distributing systems in all kinds of industrial plants. Therefore, we shall confine ourselves more directly to the problem of the distributing system in plants employing diversified machine tool processes, and individual motor drive. Individual motor drive is practically essential in shops where tool locations and manufacturing processes are constantly changing wtih a view to betterment of product and increased efficiency of production.

THE BASIS OF THE SYSTEM

Obviously, the most common sense manner of approaching the problem is to conceive of the system more or less as a railroad distribution. The load units will take energy from the system at fixed points it is true, but fixed for a varying time and varying in amount, and the system must be designed so that such movement and change in load distribution can take place without requiring extensive changes in the wiring.

To meet the conditions outlined above the system must possess the following characters:

First, it must be flexible from the point of service entry. Not only must the floor distribution be arranged to meet this requirement, but the feeder system must also be flexible so that it may be reinforced to any floor, or to any section of any floor.

Second, the distributing system must be so arranged that it can be tapped into at any point, and branches taken to any location where load units of any size may be placed.

Third, the connection of any load unit to the system at any point must not require radical changes in the mechanics of the system, but only in its carrying capacity, and the system must be such that reinforcing can be executed rapidly and at a minimum cost, without meanwhile rendering the system inoperative.

Fourth, the several parts of the system must be interchangeable as far as possible, and considering first cost, so that the number of parts is reduced to a minimum and so that they can be used for the maximum number of cases. If the location of a load unit, of such size that it requires reinforcing of the system, is changed, then it should also be possible to move the reinforcement and apply it to another part of the system, thus keeping the material busy and not merely representing capital invested and lying idle.

As pointed out above any attempt to standardize the electrical distributing system must take account of the different types of buildings into which it must be fitted. Obviously, if the system is to be flexible it must not be incorporated in the building structure. Otherwise, changes in the system will entail changes in the building—cutting, ripping out and patching. It must not interfere with or necessarily be a part of the process of building construction, as this entails added expense on both sides. It must be easily installed and easily taken down, and, if this requirement can be met, there is no reason why it should not be possible to install the system after the building is erected, or practically so. If the system is standardized it should be possible to cut and fit it all together outside of the building and only bring it in for assembly. The speed with which such a system ought to be assembled should be such as to make it possible to begin and complete its erection during the final stages of building construction. Standardization tends toward such speed and hence toward low first cost. If, then, the system is exposed and not buried in the building construction, it is obvious that at the beginning we may put in as little as need be, provided we make proper arrangements so that when necessary, as much more can be installed as the possible future demand may require.

We have talked of this system as though it were sectionalized. Sectionalizing will not only help standardizing and flexibility; it will introduce the value of interchangeability of parts and will also make it possible to partially insure against general shut-down in case of damage or injury to any part or section. From the viewpoint of production, insurance against shut-down is almost as important as insurance against other hazards.

Since the system is to be sectionalized, as well as standardized, it is necessary to begin design by determining the unit of load that each section shall supply. In other words energy demand must be standardized. This load must be determined from known data as to the average and maximum energy consumed per unit of floor area. Having determined this data, say in terms of watts per square foot floor area, it is then possible to decide how many square feet floor area shall be supplied with energy by a conductor of the most convenient and economical size and that will suffice for the largest number of conditions. The fitting of the system to such load units will tend to standardize the capacity of the various parts of the system so that a greater number of a few conductor sizes, devices, or assembly groups may be sold with a consequent reduction in cost, due to simplified production. Even should this sectionalizing require the use of more equipment, it may well be that the decreased cost of the several standard parts will act as an offset, so that the net result will be a system such as we desire at little, if any, greater first cost than the usual straight-away simple system, and a lower maintenance cost for changes.

Machine Shop Motor Loads

A study of several existing diversified machine shops showed that apparently a definite relationship existed between the ratio of floor area occupied by tools to the total floor area used for manufacturing purposes, and the average watts per square foot floor area based on a year's use of power.

In order to make clear what follows, refer to Fig. 1. This shows a purely arbitrary shop plan. The area M occupied by tools, working passage ways about them, and space occupied by active material, is called the *manufacturing area*. Any dead area left between tool groups to allow for growth of such groups is not included in the manufacturing area. The area B includes space for assembly, stock storage, packing and shipping, where few if any motor-driven tools are used, and is called *dead area*. The area of the spaces actually occupied by tools, T, and found by projecting their horizontal block plans on the floor is called the *projected tool area*. The ratio in question is

$$\frac{\text{projected tool area}}{\text{manufacturing area}} = R = \frac{T}{M}.$$

The following few cases are fairly average of well laid out shops using individual motor drive and making economical use of the manufacturing area.

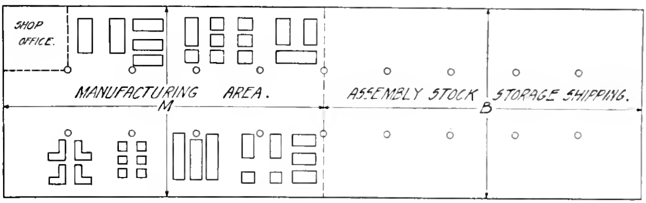


Fig. 1. Arbitrary Shop Plan Assumed for Illustration

Shop No. 1

A shop one story high, total area approximately 30,000 sq. ft., used for manufacturing miscellaneous machinery up to about 10 tons completed weight and in which no dead area existed. It was found that $R_1 = 0.15$ and the average watts per sq. ft. total area were 4.63 for both power and light.

It is worth noting that a check study of this shop made a year later and after a number of changes in number, character, size, and location of tools had occurred, showed $R_1 = 0.15$, and the watts per sq. ft. 4.74. The increased watts per sq. ft. was easily accounted for by the unusual amount of apparatus manufactured during this period.

Shop No. 2

A shop with three galleries, total area approximately 500,000 sq. ft. used for manufacturing large machinery averaging about 50 tons completed weight; dead space about 50 per cent of total area. It was found that $R_2 = 0.09$ and the average watts per sq. ft. total area for both power and light were 2.85.

Shop No. 3

A shop with one gallery, total area approximately 100,000 sq. ft. used for manufacturing largely special apparatus up to 250 kw. capacity; dead space about 50 per cent total area. It was found that $R_3 = 0.08$ and the average watts per sq. ft. total area for both power and light were 2.3.

Shop No. 4

A shop, one story high, total area 40,000 sq. ft. used for manufacturing a standard line of apparatus weighing less than two tons completed; dead space, about 70 per cent total area. It was found that $R_4 = 0.07$ and the average watts per sq. ft. total area for both power and light was 1.76.

In all of these cases, except the last, it will be seen that the watts per sq. ft., in any one shop, can be found very closely from the watts per sq. ft. in any second shop by multiplying the watts in the first shop by the ratio of R in the second shop to R in the first shop. The exception in the case of Shop No. 4 is due perhaps to the fact that much of this shop was used for storage of material from adjacent shops manufacturing different apparatus.

Thus in the case of the first two shops mentioned, we have $R_1 = 0.15$ and $R_2 = 0.09$.

Then,

$$\frac{R_2}{R} = \frac{0.09}{0.15} = 0.60$$

and,

$$W_2 = 0.60 \times 4.63 = 2.87 \text{ (nearly)}.$$

The watts in the second shop are actually 2.85.

The reverse operation also gives nearly correct results.

Now consider the third shop. We then have

$$\frac{R_3}{R_1}=\frac{0.08}{0.15}=0.53$$

and,

$$W_3=0.53\times 4.63=2.4.$$

The watts in this shop are actually 2.30.

In any two shops, therefore,

$$W_1\times\frac{R_2}{R_1}=W_2, \qquad (1)$$

and since,

$$R_1=\frac{T_1}{M_1},\ R_2=\frac{T_2}{M_2},$$

Where T is the projected tool area, and M is the manufacturing area. It follows that,

$$\frac{W_1M_1}{W_2M_2}=\frac{T_1}{T_2} \qquad (2)$$

The product WM will only be the total average load when neither shop has any "dead" space.

From (2) it follows that the product of the manufacturing area times the average watts, divided by the projected tool area is the same in all such shops.

If we had found the average watts by dividing the total average load for the entire shop by the square feet manufacturing area only, then the product WM would be the total average load. It would then follow from (2) that the total average load in any two shops is proportional to the projected tool area in these two shops, and hence, that the average watts per square foot of tool area is a constant in all such shops. Averaging a large number of diversified tools in a number of shops showed this result to be between 27 and 30 watts per sq. ft. tool area.

These results cannot be applied blindly to individual shops, to departments where all tools are alike, or to individual tools, but only to diversified tool groups of say fifty tools or more.

In this study it was found that the smaller the tools in any given manufacturing area the larger the projected tool area, and, therefore, the larger the value of R. Consequently, manufacturing processes requiring the use of small tools will require more power than processes where this condition is reversed. This is not unreasonable because the smaller the tools the larger the number that can be, and generally are, installed in a given area. Some of them will always be running. On the other hand, if two or three larger tools are installed in the same area, during some part of the time they will all be shut down.

These results are here offered with some hesitancy. A more complete investigation might lead to somewhat different conclusions. But the fact remains that these relations seem to hold through a considerable number of shops used for widely different purposes. The constants given apply, of course, only to average machine shop practice. Their values are somewhat different in factories equipped in different ways, such as, for instance, a wire and cable factory or a shoe factory.

So far we have included the power required for lighting in our computations. This, however, makes little difference, for the results are average for a day of eight hours and during this time artificial light is used relatively but a small fraction of the total time. If we assume that the connected lighting load is 1.0 watt per sq. ft. shop area, the average load for a 300-day year is about 0.13 watts per sq. ft. If the connected lighting load were 1.25 watts per sq. ft., the total average load would be only slightly greater. If we allow 0.13 watt as the average lighting load, the net average power load in shop No. 1 will be 4.5 watts per sq. ft. This shop, which gives close to average results, has no dead space. The average shop, however, has 50 per cent dead space, so that we may take as an average power load for all shops 2.25 watts per sq. ft. total area, which is close to the values obtained in Shop No. 3.

In cases such as Shop No. 4, where the average load is less than 2.25 watts per sq. ft., investigation has shown that some proportionate part of the floor area is being used for purposes not directly connected with the manufacturing being done in the shop. The range in all the shops investigated is between 1.7 and 17.1 watts average load per sq. ft.

The results of the check study made of Shop No. 1, led to the conclusion that in diversified machine shop practice not more than 15 per cent of the manufacturing area can be efficiently occupied by tools. This was again checked against a layout stated to show the maximum number of machine tools that could be efficiently placed in a given area. The result was $R=0.153$.

It is also necessary to find average peak loads that will affect the design of the distributing system. The load factors frequently assumed for preliminary work are 40 per cent connected load as average, and 60 per cent connected load as peak. These values do not give correct results in any of the shops investigated.

A method of determining the average load from the tool layout has been given. To determine the average peak load that must be considered in proportioning the copper, we shall apply the law of probability to the starting and stopping of motors.

It is a fair assumption that in any large diversified machine shop at any moment just as many motors are as likely to stop as to start. Otherwise, in time all motors would be either running or standing still simultaneously.

If, then, all the motors in a shop are of the same size it is likely that at any moment just as much load will be in the process of being connected to the distributing system as will be in the process of being disconnected from it. Under these conditions the average peak load will not be much greater than the average load. If the motors are of various sizes then we must weight their chances of being started or stopped with their individual loads.

As most tool motors are compound wound, are usually selected for a duty that will rarely be demanded of them, and start under light load, the starting current inrush will not be marked. In Shop No. 1, the average motor horse power of 133 motors is approximately 6.2, yet the average load is but 1.2 kw. or 1.3 developed horse power per tool. The peak load in this shop would be 3.5 times the average load to equal the connected motor horse power converted to kilowatts. Actually, the peak load does not exceed twice the average load, so that, on the average, the motors are never required to develop more than 41 per cent of their rated output.

What follows must be considered rather as outlining the possibilities of the method than as developing its detail application. Space in this paper is not available for a complete discussion, but as the writer believes the matter to be new, a brief presentation here seems advisable, even if only to bring about discussion.

Let N be the number of motors in the group. Let p be the fraction of working time that, on the average, any motor is running. Then, since on the average just as many motors are connected to the system as are disconnected from it at any one moment, Np motors will, on the average, be always connected, and, presumably running. The factor p will vary from less than 0.5 to 0.9 in factories engaged in different industries and kinds of work.

If W is the average load, $\frac{W}{Np}$ is the average load per motor. If H is the average rated horse power of all the N motors, $0.746\frac{H}{E}$ is the average demand in kilowatts at full rated horse power, where E is the average full load efficiency. Then,

$$f=\frac{WE}{0.746\,NpH}$$

is the average fractional demand at which the Np motors operate, and from this their average efficiency e at this load can be determined. Then,

$$h=\frac{We}{0.746\,Np}$$

is the average horse power developed. As we have seen, in diversified shops, there is reason to believe that f will not generally exceed 0.5.

Obviously, the minimum probable load will occur when the Np smallest motors are connected to the system simultaneously, each developing a fraction, f, of its rated horse power. Similarly, the maximum probable load will occur when the largest Np motors are connected to the system simultaneously.

The probability that any particular group of Np motors will ever be connected to the system simultaneously is p^{Np} and is very small unless N is small.

We may, therefore, conclude that the probability that the smallest probable load will be exceeded at any time is a certainty. Also the probability that the load will ever be less than the smallest Np motors is infinitely remote or zero. Similarly the probability that the load at any time will be less than the largest Np motors is a certainty, and that it will ever be greater, infinitely remote or zero.

If the intermediate probable load values are infinitely finely graded between maximum and minimum, two simple probability curves can be drawn, such as shown in Fig. 2, intersecting at the average load. The probability that at any time the actual load will exceed or be less than this average value is the same. Therefore its probability is 0.5.

We are interested only in loads larger than the average, and wish to find what the chances are that any load above the average will be exceeded. Let us take a load from Fig. 2 whose probability of being exceeded is 0.01. This load is 99 per cent of the maximum probable load. We wish, then, to find the probability that this load will be exceeded at least once when we are willing to risk even chances on it. By the well known formula, $n = -\frac{\log 2}{\log (1-c)}$ where C is the probability that the load will be exceeded (in this case 0.01), and n is the number of trials necessary to insure that the load will be exceeded at least once, it follows that $n = 69$.

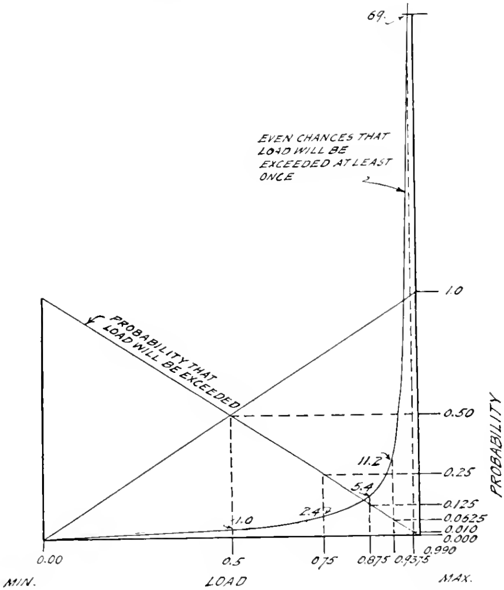


Fig. 2. Probability Curves for Evenly Graded Load.
Average is Mean $= \frac{\text{Maximum} + \text{Minimum}}{2}$

What interpretation shall we give to the word "trials"? There are, let us say, 100 motors in the group of which, on the average, 0.6 or 60 motors are always connected to the system. Let us assume that, on the average, each motor is in operation six minutes and is idle four minutes. Consequently, in eight hours each motor will be connected to the distributing system 48 times, and the whole 100 motors 4800 times. This, we may say, gives opportunity for the load to increase 4800 times a day. Therefore, out of every 69 changes or, on the average, ten times an hour, the load will exceed at least once 99 per cent of the maximum probable load. On this same basis it would require an infinite number of chances for the load probably to reach once the maximum probable load whose probability of being exceeded is zero. In this manner, we may plot a curve of chances such as shown in Fig. 2.

The question then resolves itself into this: Is it worth while to design the distributing system to carry a load that, on the average, will be imposed upon it once every six minutes? Will it not be sufficient to set the circuit breakers on the mains for this load, or even for the maximum probable load, and, the Underwriters being willing, design the copper for the average load, or something above it, since the average load (probability 0.5) would probably be exceeded every trial? That is, the chances are even that it will be exceeded.

In all of the foregoing much has been assumed and many working conditions left out of consideration. Motors in machine shops are not always graded so that the probability curves will approach the form of those in Fig. 2.

Generally, however, the motor sizes are so distributed that most of the loads within the probable range can be made up by a number of combinations of different size motors. When this is the case, fine grading of the load between maximum and minimum can be assumed. In such cases, the probability curves will take the straight line form shown in Fig. 3. The average load is not necessarily also the mean, as was assumed in constructing Fig. 2.

Sometimes a particular load in the range of probable loads can be made up in many more ways than any other load within this range. This increases the probability of its occurrence, and decreases the number of chances necessary to insure that it will be exceeded.

Again, a number of relatively large motors may be included in the group.

Assume, for instance, that in the entire group there are five motors alike; then, with $p = \frac{2}{3}$ one such motor will be off $\frac{1}{3}$ of the time and on $\frac{2}{3}$ of the time. Two such motors will be simultaneously off $\frac{1}{9}$ of the time, and on simultaneously $\frac{4}{9}$ of the time, and five such motors will be on simultaneously

$^{32}/_{243}$ of the time and off simultaneously $^{1}/_{243}$ of the time. The periods being given by "off" $= \left(\frac{1}{3}\right)^n$ and "on" $= \left(\frac{2}{3}\right)^n$ where n is the number of motors being considered together. Thus, if these motors were 5 h.p., this group alone would probably introduce a peak every 1.25 minutes amounting to 26 kw. The probability of this load is $^{32}/_{243} = 0.13$, and must be taken into account in constructing the probability curve for the entire group. If there are several such cases in the group, then the probability that any combination of them will occur simultaneously is the product of their individual probabilities.

All of these conditions may bring about an irregular probability curve rather than the straight line curves shown in Figs. 2 and 3.

If, however, the number of motors in the group is relatively large (50 or over), and the number of similar large motors in any case is not very great, or their combined horse power not a very great part of the total horse power of the group, and also if the motors as a whole vary considerably in rating among themselves, the probability of any such combination is small and a sufficiently close approximation will be obtained if infinitely fine grading of load is assumed; provided only that the probability curves intersect at the average load and that the sum of the probabilities that any load will be exceeded and that it will not be reached is always unity.

As a concrete example let us take the case of a tool-making department in the Sprague Electric Works. The motors are as follows:

Horse Power	Number	Total Horse Power
10	1	10
7½	5	37½
5	8	40
3	10	30
2	17	34
1	17	17
½	4	2
¼	2	½
Totals	64	171

The average horse power is therefore 2.67.

If we put $p = 0.6$ and $f = 0.5$, then the demand per motor when running is 1.38 kw., assuming an average efficiency of 0.725. The average number of motors connected is $0.6 \times 64 = 38.4$. The total average load is $1.36 \times 38.4 = 52.2$ kw. The area occupied by the tools is 2049 sq. ft. At 27 watts

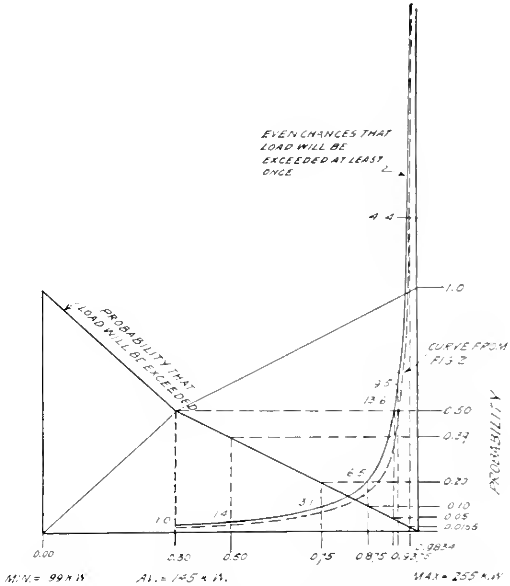


Fig 3. Probability Curves for Evenly Graded Load. Average is 0.3 of Range

per sq. ft. the average load should be 55.3 kw.

The manufacturing area is 13,632 sq. ft. Therefore, $R = 0.15$, which is the same as Shop No. 1, and the average load per sq. ft. of manufacturing area should be 4.5 watts. From the figures given above, it is $52{,}200 \div 13{,}622 = 4.0$ watts per sq. ft. a remarkable agreement when we consider the differences between the two shops.

Since $p = 0.6$, the maximum probable load should be that of the largest 38 motors. It is 145.5 rated horse power, or nearly 74.5 kw. actual average demand. The minimum probable load is 45.5 rated horse power or 23.3 kw. actual average demand. The average load is 70 per cent of the maximum load and, therefore, lies toward the maximum load 0.55 of the range between maximum and minimum. Here the probability curves for this case must intersect, and the probability of this load is 0.5.

If we drop off the single 10-h.p. motor and keep the number of motors connected constant, the next lowest probable load is 137.5 rated horse power or 95 per cent of the maximum probable load, and 93 per cent of the range between minimum and maximum. The probability that this load will be exceeded is 0.07. But the next probable higher load is the maximum probable load. So the maximum probable load must be used as probable average peak. It is, therefore, about 43 per cent greater than the average load, or 56 per cent of the total connected load.

Among these motors there is a sub-group of five, all of which are rated at 7½ h.p. or 3.6 kw. average demand. The total demand of the sub-group may occur $(0.6)^5$ or 0.08 of the time. However, these motors are only 1/9 of the total number connected at any time and, therefore, cannot materially affect the results, particularly in view of the fact that the 45 largest motors constitute such a large portion of the total horse power.

Let us next examine Shop No. 1 for probable peak. This shop is equipped with fairly large tools—48-in. borers and the like. The motor data follow:

Horse Power Rating	Number	Total Horse Power
¼	2	0.5
½	4	2.0
¾	6	4.5
1	4	4.0
1½	1	1.5
2	15	30.0
2½	1	2.5
3	17	51.0
4½	1	4.5
5	32	160.0
7½	15	112.5
10	23	230.0
15	8	120.0
20	3	60.0
35	1	35.0
Totals	133	818.0

Average horse power 6.15.

Therefore, $N=133$, and from the data presented above, average load, $L=145$ kw. Hence, the average demand per motor is 1.1 kw. The average demand of a 6.15 h.p. motor at 50 per cent load is 2.8 kw. Therefore, $Np=\frac{145.5}{2.8}=51$, and $p=\frac{51}{133}=0.38$.

The Np largest motors, the average rating of which is 11 h.p., at 50 per cent load demand 255 kw. The Np smallest motors, similarly demand 99 kw. The probable load variation, therefore, lies between 99 kw. and 255 kw.—a range of 156 kw.—so that the average load of 145 kw. lies, toward the maximum, 30 per cent of the range. At this point the probability curves intersect at $C=0.5$ as shown in Fig. 3.

The range and grouping of the motors is such that practically any load between average and maximum can be made up in a number of ways. The sub-groups of 5-, 7½-, 10-, and 15-h.p. motors, constitute a possible source of irregularity. This can be tested out by constructing a separate probability curve for these groups taken together. The probable maximum load introduced by these 78 motors averaging 8 rated h.p. is about 100 kw. when the largest 30 motors are connected. The probability that this load will occur in just this way is 0.38^{30} and is very small. It will be found that these motors do not introduce a serious complication, and we shall assume that the number of ways in which any load can be made up is sufficiently large to warrant the assumption of fine grading and straight line curves each way from the average.

The "trial" curve is constructed and, for comparison, shown in Fig. 3 in connection with the similar curve from Fig. 2.

The tools in this shop are generally large enough to warrant our taking the average working time at 30 minutes. There are, therefore, a probable 2128 total chances for the load to increase. Taking 75 per cent of the range, it appears that a load of 215 kw. will be exceeded at least once in every 3.1 trials. That is, 686 times a day or about 86 times an hour.

It we take 95 per cent of the range, or 247 kw., the trials necessary to insure its being exceeded at least once are 19.5; that is, 104 times a day or 13 times an hour. We shall be safe in designing the distributing system for this load, and calling the probable peak 247 kw. or 60 per cent more than the average and 33 per cent of the total connected load. The main circuit breakers would have to be set above this. Actually the peak in this shop reaches the maximum probable load, and, occasionally, somewhat more.

We shall assume that in the preliminary design of distributing systems in diversified machine shop practice it is safe to assume that the peak load which must be considered in proportioning the copper, will be 50 per cent in excess of the average when the average is based on the values of watts per sq. ft. given above.

We are now able to lay out the backbone of a distributing system even before we know how the power will be used or how the load will be distributed. It is merely necessary that we order copper enough so that the feeders and mains can carry a load of 2.25 watts per sq. ft. of floor area. But the method of installation must be such that as soon as we get the tool layouts reasonably well fixed and can determine average and average peak loads in the various departments, we can quickly distribute the copper accordingly. These tool layouts will come along about the time the tools arrive—sometimes even later, so that if the distributing system is at all rigid difficulties will be encountered.

At least one proper solution of the problem will be found in the use of a backbone main on each floor; or, in wide buildings or heavily loaded buildings, a backbone main on each side of each floor. These mains are considered as semi-permanent, but so arranged that any section of them can be removed or reinforced. The mains will be provided with permanent taps at every bay or at every other bay, the taps being so arranged that branches or reinforcement can be connected to them without disturbing the permanent equipment. Branches to motor starting boxes or to tool cutout boxes, will be made only from these taps. The distribution from tap points to load units also consists of units attached to the main system at the permanent taps and so each such branch may be shifted in its entirety from tap to tap. It becomes, in fact, a part of the load unit as much as the motor or the controller.

A one-line diagram of the system is shown in Fig. 4. The size of conductors and circuit breakers given in this diagram are those found most generally useful for a system based on the watts per sq. ft. values given above. The diagram indicates the trunk main on two floors, or rather the space provision therefor, as the main may not be continuous. Tap points are shown with branches or taps to power cutout boxes where the fuses protecting the branches to tool groups are located, each tool being provided with a cutout switch without fuse. In some cases where tools are more or less connected in their work and belong together or where the motors are small fractional horse

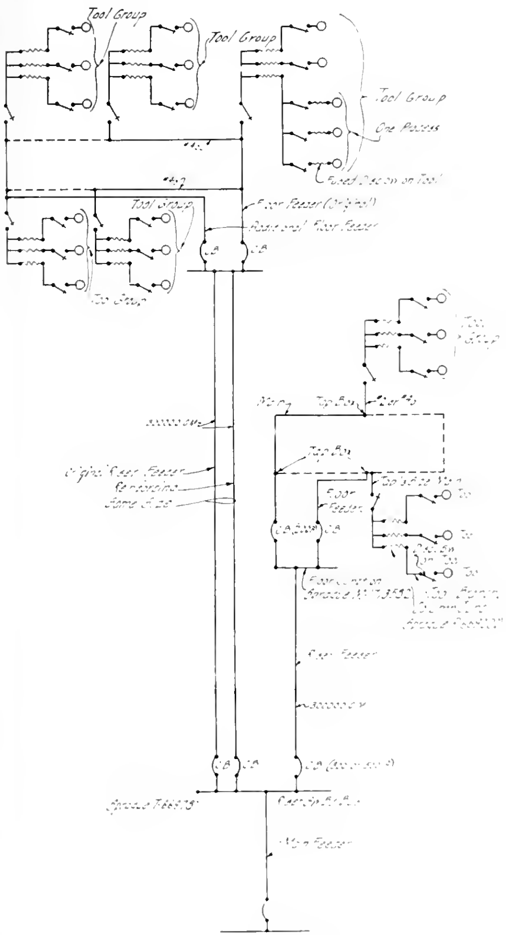


Fig. 4. One Line Wiring Diagram

power—several tools may be looped together on a single branch, in which case the cutout switches on the tools as well as the branch should be fused.

By thus concentrating the fuses at cutout boxes where the change in size of conductors between taps and branches is considerable, not only is the tool branch as well as the motor and starter protected, but also, and more important, no main fuse or other safety device is required in the cutout box. Furthermore, if the tap is not less than one-third the size of the main in current carrying capacity, is not unreasonably long, and is run in conduit, no safety device is required where it joins the main. This throws the safety device next in circuit to the tool branch fuse back to the circuit breaker protecting the feeder that supplies the main. The advantage of this arrangement is that in case of a succession of overloads on individual motors, branch fuses protect the motors and will isolate each case of trouble, while shut-down of a tool group or a number of such groups will not occur unless conditions become generally dangerous. A succession of safety devices not differing greatly in capacity is a frequent cause of general shut-down due to isolated cases of trouble, particularly if fuses are used in series. It is worth while paying some money for this kind of insurance.

The mains are arranged so that they may be cut in sections and each section fed separately, or they may be continuous and fed at one point. Innumerable combinations are possible depending on the load distribution and its development. The main, being of the same size throughout will be sectionalized so that the load fed by any section will not exceed its current carrying capacity, or if the current carrying capacity is necessarily exceeded, the main may be reinforced.

All floor feeders are the same size as the mains. At the floor junction each floor feeder to a main or section thereof is connected to a common bus through a one size circuit breaker which thus protects both floor feeder and main.

On the floor then, all circuit breakers, conduits, and conductors used for main distribution are the same size. Since the location of cutout boxes is purely arbitrary we may select a size to feed a given and convenient number of motors of average horse power and make these cutout boxes all of the same size.

As far as possible the distribution of floor junctions will be determined as follows:

Assume that a No. 4/0 conductor is a convenient size for the mains. Its current carrying capacity is 225 amperes which, at 240 volts is 54 kw. Allowing for drop and for peak load, say that a No. 4/0 main will feed 35 kw. average load. This, at 2.25 watts per sq. ft. floor area, means that every 11,000 sq. ft. floor area will require a main. Suppose the building is 75 feet (3 bays) wide, and a main will be eventually run along both rows of columns, then one main will supply about 300 linear feet of building. Allowing for mains running both ways, the riser points will be 600 ft. apart.

Structural conditions may, of course, make it advisable to somewhat depart from this. On this basis a building 500 ft. long and 75 ft. wide, would have two riser points spaced about 300 ft.

At each junction location there will be a riser point if the building is more than one story high. Generally a location for these risers can be found on a fixed tower or stair wall, and a series of nipples provided over each other in each floor, through which the risers can be run.

Generally a single riser of appropriate size will be run to each floor junction. Sometimes two are necessary, and occasionally it may be necessary to install special risers that do not pass through a floor junction but run directly to some special apparatus on any floor, such as a test department. Each of these risers originate in a switchboard on the first or lowest floor, usually a convenient space back of the wall on which the riser runs can be found for use as a switchboard room. See Fig. 5. The switchboard room is provided with a pit below the first floor level to serve as a manhole in the incoming subway system if such exists. A removable floor is provided at the first floor level.

Thus the risers are quite as flexible as the floor distribution and as little or as much copper and other material put into the riser as necessary to meet any particular case.

Since the riser conductors are all the same size, the circuit breakers on the switchboard will also be all of the same size, and the board may be designed so that as many as are initially necessary may be installed at first, and more later as conditions may require. Then, since everything else in the system has been standardized, the switchboards may also be standardized. This gives the added advantage that all space requirements may be determined in advance when the building plans are under consideration—generally long before any subdivisions of load or detail tool layouts have been decided upon.

We have now outlined the system from the tool cutout box to the switchboard, and must go back for a moment to the tool branches. A simple flexible method of running tool connections from the cutout boxes in buildings of mill construction can be easily found by running them on the ceiling of the floor below. Boring through the floor is an easy matter. But in modern buildings of reinforced concrete the problem becomes serious and the process costly, particularly if changes are frequent. However, for lack of a better type, the so-called "floating" wood floor consisting of a heavy under floor and a lighter upper or finished floor has been commonly used, the two floors laid at 90 degrees to each other. The under floor is usually of planks $2\frac{3}{4}$ in. by 8 in. or 10 in., so that by systematically omitting planks a system of under floor passage-ways may be obtained in which the tool connections can be fished in flexible conduit. These passage-ways should be crossed at suitable intervals, usually on the column axes, by trunk trenches with removable covers in which the connections can be laid from the cutout boxes on the columns. The only floor cutting necessary is that lengthwise of the upper floor from the nearest passage-way to the tool, grooving the under floor to receive the conduit and then replacing the upper floor strip removed. In this way the cost of making and changing tool connections is materially reduced, and the finished floor may be put down before the tool layouts are determined.

We thus start out with a predetermined switchboard space, figured by putting together enough standard switchboard parts to meet maximum conditions, a hole in the wall of the switchboard room so that conduits may pass through to the riser, a series of nipples in each floor, a standard system of hanger inserts arranged for in the ceilings, a system of under floor passages and trenches determined, the necessary clearances recorded and established, and the building may go ahead, no matter for what manufacturing process it is to be used.

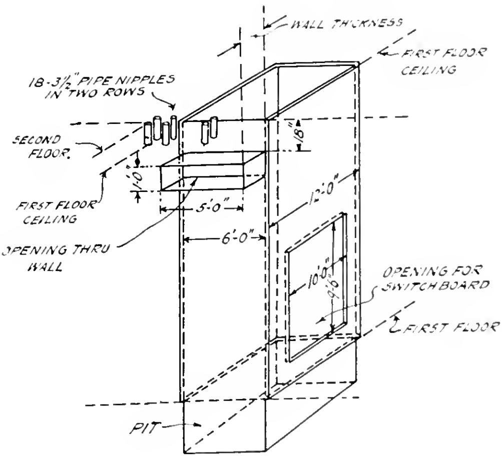


Fig. 5. Switchboard Compartment for Risers

During the preliminary work, of course, co-ordination of plan, priority, and right of way must be established between the work of the various mechanical trades—heating, sprinkler, plumbing, cranes, etc.

Thus far in this discussion, the distribution for lighting has not been touched upon, because the same general arguments apply and it seemed wise not to confuse the issue. It is believed that the examples of the application of this method given in Part II will suffice.

Electricity in Beet-sugar Factories

By E. M. Ellis

Los Angeles Office, General Electric Company

Progress and economy demand the electrification of our railways and industrials. The production of beet sugar is one of the later industries to adopt electrification. The following article gives a readily intelligible description of the processes involved in the production of beet sugar and explains how greater reliability and economy can be secured by electrification. The many illustrations show the simplicity and flexibility of electric drive. The application of electricity is equally advantageous in the manufacture of cane sugar; see "The Electrification of Cane-sugar Factories" by A. I. M. Weintraub G.E. Review, 1914, Jan., p. 74 and Dec., p. 1204; and "Electricity Applied to the Manufacture of [Cane] Sugar" by P. S. Smith, 1913, Aug., p. 571. In a forthcoming issue we expect to publish "Economies of Electric Drive in Cane Sugar Mills."—Editor.

The shortage of sugar resulting from the War has brought the public to a realization of the value of sugar as an article of food. The destruction of the sugar factories of France, Belgium, and Russia, and the cutting off of the sugar supply from Germany and Austria-Hungary have compelled the Entente Allies to invade the Cuban market which has been the principal source of supply for the United States.

In the season of 1913–14 there were produced in the world 20,602,768 short tons of sugar, of which 9,433,783 tons (46 per cent) were from the sugar beet, and the balance from the cane. The consumption of sugar in the United States during this period was 4,396,898 tons (21.5 per cent). Of this amount, 55.66 per cent was cane sugar from foreign countries (mainly Cuba), 27.84 per cent was cane sugar from Louisiana, Texas, and insular possessions, and the remaining 16.50 per cent was domestic beet sugar. The beet-sugar factories have increased from 78 in 1913 to 92 in 1917.

Climatic conditions determine whether cane sugar or beet sugar should be produced. The sugar cane requires a twelve-month growing season and an absence of frost in the ground; the sugar beet can be matured in half that time and, as it is raised from seed each year, the frost does not affect it. The cane is therefore confined to the tropics, while the beet is suited to the temperate zones where the average temperature during the growing season averages 70 deg. F.

The beet seed, which formerly was nearly all imported from Germany on account of our inability to compete in price and quality, is now to a large extent imported from Russia; but the cultivation of seed has been started in this country and this will make us independent of an outside supply. The imported seed is distributed to the planters by the various sugar factories, in return for which the planter contracts with the factory from which he receives his seed for his crop or "acreage." Sugar beets will grow in soil containing considerable alkali and require comparatively little moisture. In Southern California the seed is planted in January, February, or March; and the first of the crop is ready for harvest about July 1st, the harvest extending to the first of December. The dates are governed by the conditions of the crop and also by the factory in order that the beets will not be brought in faster than they can be handled. It is necessary to do considerable work in the beet fields while the beets are growing. They are planted very thickly and after a few weeks of growth are thinned by hand. Due to Government regulation and competition with cane sugar this operation requires very cheap labor, secured at present to a large extent from Mexico. After the beets are harvested the tops and tips are cut off and the beets thrown in small piles ready to be hauled either to the factory direct or to the railway beet dumps to be loaded in cars, depending upon the distance to the factory. The beets are left in the ground, however, until the factory is ready for that particular acreage.

Storage bins are provided in the beet shed adjacent to the sugar factory, and have a capacity to insure an uninterrupted daily supply independent of weather conditions.

The process of beet-sugar manufacture, briefly stated, consists of washing and slicing the beets, extracting the sugar content by the diffusion process, clarifying and evaporating the juice, graining out the sugar, separating the crystals from the molasses, and drying the sugar before it goes into the bag. The heating, clarifying, evaporating, and graining processes are all carried on in vessels heated by high- or low-pressure steam. Considerable power is required to work up the beets, pump the juice, and separate the crystals. The low-pressure steam is obtained from the power units which operate against the back pressure

Fig. 1 Main Factory and Warehouse. Anaheim Sugar Company, Anaheim, Cal.

Fig. 2. Power Plant Consisting of One 750-kv a., 3000-r p.m., 480-volt Alternator with Direct connected Exciter, Driven by a Non condensing Curtis Steam Turbine. Switchboard consists of one generator and exciter panel, six feeder circuit panels and two lighting panels. Anaheim Sugar Company, Anaheim, Cal.

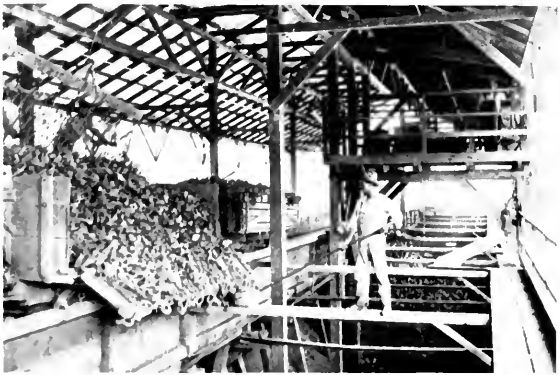


Fig. 3 Beet Bins showing Method of Unloading Wagons by a Motor driven Hoist and Obtaining a Sample for the Tare Room American Beet Sugar Company, Chino, Cal

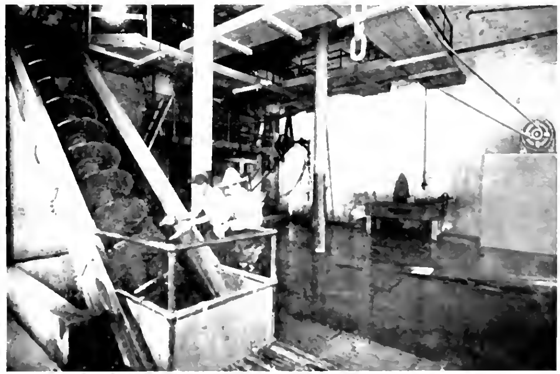


Fig. 4 Beet Screw for Elevating the Beets from the Flume to the Washer at the top American Beet Sugar Company, Chino, Cal.

of the low-pressure system. Fig. 2 shows the interior of the power plant of an electrically driven factory employing a steam turbine-driven unit.

Fig. 3 shows a wagon load of beets being dumped into what is called the "beet shed" for storage. The illustration also shows the method of obtaining a sample of the beets to be taken to the tare room.

The tare room is of particular interest to the farmer, because it is here that the tare weight of his load is decided. About one bushel of beets is taken from the wagon or carload, trimmed with a knife and mechanical brushes, and then weighed. The difference between this and the original weight is the tare. The cleaned or "tared" beets are cut in halves and one half tested for sugar content and purity; the results obtained are used as the basis for the entire load.

The beets are taken from the beet sheds by means of water in a flume and are floated past a Dalton separator or weed catcher, shown in Fig. 5. The flow of the beets through this flume is quite rapid in order not to allow the beets to remain in the water too long, as a loss of sugar amounting to about 0.2 to 0.5 per cent would result.

Upon their entrance into the factory the beets are elevated to the washer by means of a beet wheel, air lift, or screw, shown in Fig. 4. Here they are treated with warm water and are washed by means of mechanical brushes and rotating paddle, and are then passed through a tailing separator to the beet elevator. The elevator is an endless bucket conveyor which carries the washed beets to the top of the building where they are emptied into the hopper of an automatic weigher, shown in Fig. 9.

The beets pass from the hopper of the automatic weigher into the beet storage bins directly over the top of the beet slicers or cutters, shown in Fig. 6. In these cutters the beets are cut into long, V-shaped sections, called "cossettes," 1/8 in. thick and from 1 in to 3 in. long, to expose as much surface as possible. They are cut by means of gang cutters or knives, arranged on a rotary drum.

From the slicers, the cossettes are conveyed either by belt conveyors, as shown in Fig. 7, or chutes into the diffusion cells which have a capacity of from two to five tons of sliced beets, and are arranged in a battery usually ten to fourteen cells in series. In these cells warm water is circulated first through the exhausted chips and last through the fresh cossettes, extracting 85 per cent of the sugar content.

The exhausted pulp with the entrapped fresh water is periodically discharged through an opening in the bottom of the cells and is then pumped to the silo shown in Fig. 15. Here the water is strained from the pulp and returned to the factory for fluming the beets. The pulp is largely used directly as cattle feed, although some factories have a pulp drying plant where it is dried and packed for storage.

The juice taken from the cossettes is measured in tanks and is pumped to lime-mixing tanks, where a solution of lime milk of about 20 per cent Baume is added to the juice in order to furnish a filter base and also to act as a clarifying agent. The juice is then pumped to the first carbonation tanks where it is saturated with carbon-dioxide gas. This gas is taken from the lime kilns and is pumped into the juice at about four pounds discharge pressure. From the first carbonation tanks the juice is pumped under a pressure varying from 40 to 70 pounds to the first carbonation presses or filters. Here the juice is filtered, removing the dense lime cake which is discarded from the process. This cake is either used for fertilizer on beet fields or dried in rotary kilns and used in the Steffens process.

The juice flows from the first carbonation presses through a re-heater to the second carbonation tanks. This process is continuous, that is, when the system is made up of two or more tanks the juice is saturated with carbon-dioxide gas as a clarifying agent in the first and is boiled in the second. From the second tanks the juice is taken to the second carbonation presses and is filtered under a pressure of about 20 pounds, removing additional solids consisting mostly of lime. The cake from these presses is returned to the first carbonation juice; and the juice from these presses is saturated with sulphur-dioxide gas and a filter base of Keiselguhr is added. It is then passed through a gravity-bag filter and sometimes also through a tube boiler to the first-effect evaporators.

The juice enters the evaporators at a density of 13 deg. Brix. and the surplus water is evaporated, leaving the juice at a density of about 60 deg. Brix. (Degrees Brix. represent the amount of solids in the solution.) These evaporators are arranged in multiple effect, using exhaust steam on the first-effect and the vapors from the juice on the second-effect, and so on to the end of the last-effect

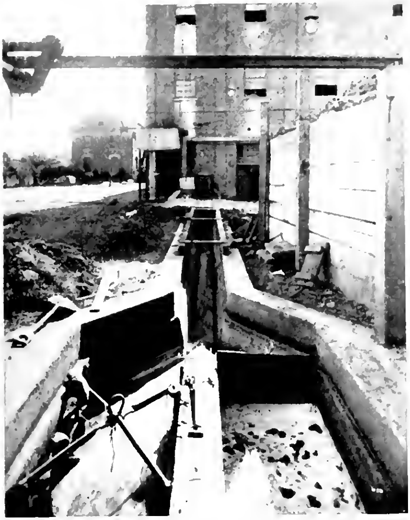


Fig. 5. Beet Flume showing a Dalton Weed Separator at the Entrance to the Building. A Motor Operated Hoist Removes the Crib with the Weeds and Trash. Anaheim Sugar Company, Anaheim, Cal.

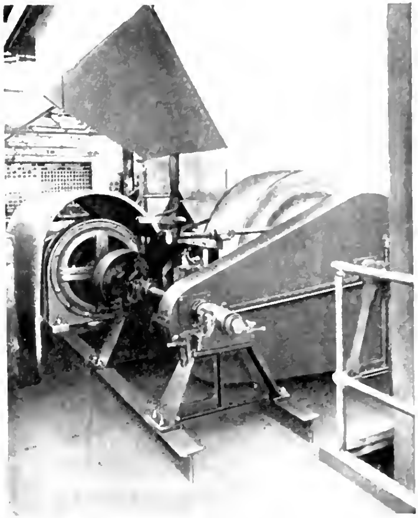


Fig. 6. Beet Slicers Driven by One 60 h.p., 750 r.p.m. Squirrel-cage Motor through Friction Clutches and Chain Drive. Anaheim Sugar Company, Anaheim, Cal.

Fig. 7. Cell Floor showing Diffusion Cells and Cossette Conveyor in the Center with Heaters, Filter Presses, and Carbonation Tanks at the side. American Beet Sugar Company, Chino, Cal.

Fig. 8. 30 h.p. [illegible] r.p.m. Squirrel-cage Motor with Double-end Connection Driving Pulp Pumps. A juice pump is shown to the right driven by a [illegible] h.p., 1000 r.p.m. squirrel cage motor also suspended from the ceiling. American Beet Sugar Company, Chino, Cal.

where the vapors enter the condenser. In the first-effect evaporator the body is under a pressure; in the second-effect it is under a vacuum of 5 inches; in the third under 15 inches; and in the last under 25 inches.

The juice is pumped from the evaporators to storage tanks and is drawn as required into the vacuum pans. In these pans the juice is boiled to a grain. The pans generally boil under a vacuum of about 26 inches and use steam at 60 pounds pressure for heating. About five hours is required for boiling a pan of brown sugar. From these pans the fillmas, or concentrated juice and sugar, is dropped into a crystallizer where it is kept agitated in order to crystallize under a uniform temperature for a period of 60 to 70 hours. From these crystallizers the fillmas is drawn off to mixers, where it is kept agitated until worked through the brown-sugar centrifugal machines. These are called "brown" centrifugals, due to the fact that the mass is dark in color and contains considerable impurities, although the sugar remaining in the machine is white in color. These centrifugals are operated at about 1000 r.p.m. and throw off through a screen lining all the liquid, retaining the solids. The solids consist mainly of brown sugar and some salts or impurities. The liquid thrown off is known as molasses (not the common commercial molasses owing to a considerable amount of impure content) and is approximately seven per cent of the total weight of the beets. This molasses is discarded from the process and is sold as a factory by-product to distillers of alcohol, or it is worked over for further sugar extraction by the Steffens process. Sometimes the molasses is sold to be mixed with ground feed for stock. As the molasses is thrown off from the centrifugals, the sugar is washed with cold water. Because this wash water when thrown off carries with it a high sugar content, it is transferred back into the process in the vacuum pans, and is called the "low wash."

The brown sugar discharged from the sugar centrifugals falls into a scroll and is conveyed to a melter tank where it is converted into a solution mixing with thick juice from the evaporators. Then it is pumped into the "blow-up" tanks where it is saturated with sulphur-dioxide gas for removing the impurities. From these tanks it is pumped under pressure through filter presses and is passed through gravity filters. It is then pumped into storage tanks on the vacuum-pan floor. In the vacuum pans it is mixed with the "high-green" syrup and "high-wash" syrup, obtained later in the process from the "white" centrifugals, and is boiled to a grain of the size desired. When finished, the fillmas is dropped into the mixer from which it passes into the white-sugar centrifugals. These machines are called "white" centrifugals because it is here that the pure sugar is obtained, and this sugar is considerably whiter than that obtained from the "brown" centrifugals. The white centrifugals are practically the same as the brown centrifugals in operation, and the liquid thrown off from the white centrifugals is known as the "high-green" syrup. When the mass enters it is brown in color, but as the syrup is forced out the sugar gradually whitens. After the mass has spun for about sixty seconds it is washed with cold water while revolving. This wash water when thrown off also carries with it a high sugar content and is known as the "high-wash" syrup. These high-green and high-wash syrups are carried through a further process where sulphur-dioxide gas is injected, and then they are pumped into storage tanks on the pan floor and are used as has been outlined. The centrifugal is then brought to a stop and the sugar scraped from the sides of the basket and discharged through an opening in the bottom. The sugar discharged from the white-sugar centrifugals is conveyed by scrolls and elevators to the storage box high up in the building. It is fed from the storage box to the granulator, or dryer, where the moisture is evaporated from the crystals. From the granulator, the sugar is graded over mechanical screen devices and is discharged into hoppers below. From these hoppers the sugar is drawn off into bags which are properly labeled for the various size crystals in the different hoppers. The sugar is graded according to the size of the crystal and not according to the purity of the sugar, as the purity, or quality, of a particular factory remains practically the same throughout.

The Steffens Process

The molasses which is thrown off from the brown centrifugals is treated in what is called the "Steffens" plant, and approximately one-half the molasses is reclaimed as commercial sugar. This molasses is pumped into storage tanks and is then drawn off into solution mixing tanks where it is diluted with cold water to a density of about 12 deg. Brix. From these tanks it is pumped over pre-cooling coils and drawn into reaction coolers. In these coolers powdered lime is added with which the sugar combines at a temperature

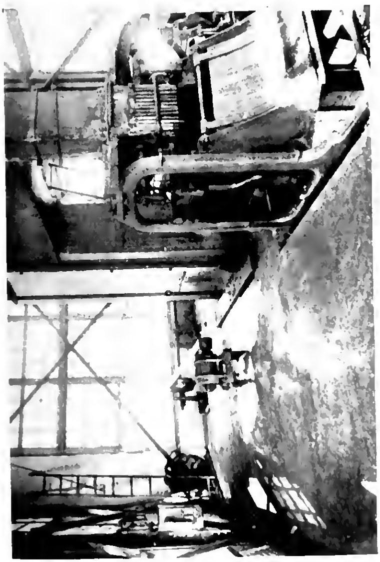


Fig 9. Beet Elevator and Automatic Weigher Anaheim Sugar Company, Anaheim, Cal

Fig 10. Steffens Main Drive with a 100-h.p., 750-r.p.m. Motor. Los Alamitos Sugar Co., Los Alamitos, Cal.

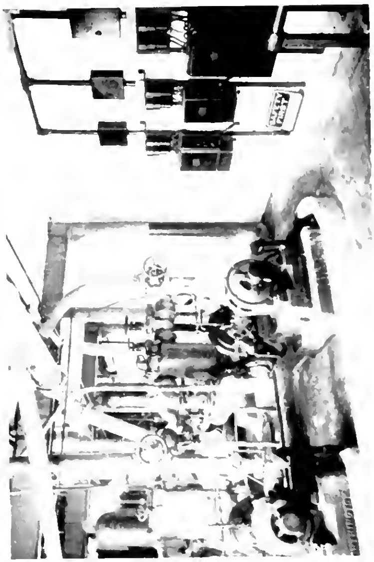


Fig 11. First and Second Carbonation Pumps With Direct Coupled Motors American Beet Sugar Company, Chino, Cal.

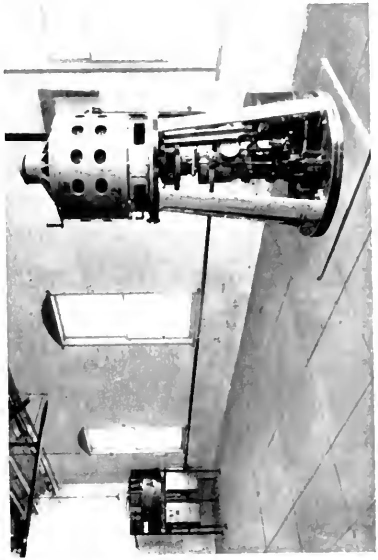


Fig 12. 150-h.p., 750-r.p.m. Squirrel-cage Vertical Motor Direct-coupled to a Deep Well Water Supply Pump. Anaheim Sugar Company, Anaheim, Cal.

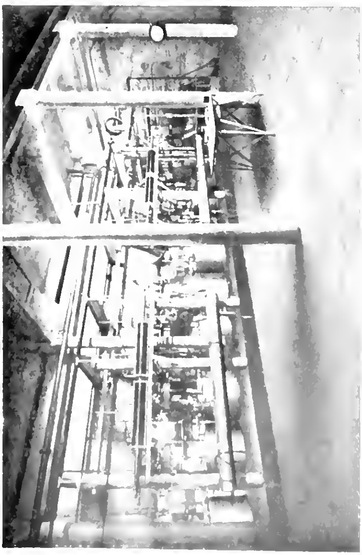


Fig. 13. Eight 40-in. Brown-sugar Centrifugals Group driven by a 75-h.p., 750-r.p.m. Motor. American Beet Sugar Company. Chino, Cal.

Fig. 14. 20-h.p., 1000-r.p.m. Vertical Induction Motor driving a Circulating Water Pump Serving the Cooler at the Right. Los Alamitos Sugar Co., Los Alamitos, Cal.

Fig. 15. Pulp Silo showing the Outgoing Pulp Line, the Strainer Tower and the Return Water Pipe. Los Alamitos Sugar Company, Los Alamitos, Cal.

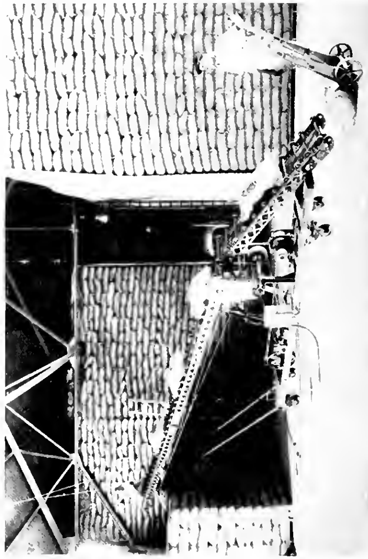


Fig. 16. Interior of Sugar Warehouse showing a Motor-driven Sugar Stacker. American Beet Sugar Company, Chino, Cal.

low enough to prevent the lime from slacking. While the lime is being added, this temperature is maintained by a cold brine solution flowing in the coils of the reaction coolers in order to absorb the chemical heat. From these coolers the solution is pumped through filter presses. The cake from the filter presses is mixed in tanks with wash water from the first carbonation presses. This saccharate is used for liming the first carbonation juice and introduces the sugar from the Steffens plant at this point in the factory process. The waste water from these presses is heated to the boiling point and pumped through additional presses called hot-saccharate presses. The waste water from these latter presses has formerly been discarded but is now being used to some extent in the manufacture of potash. About five per cent dry potash is obtained by evaporation. The cake from the hot-saccharate presses is mixed with the cold press cake in the saccharate mixing tanks before being pumped to the first carbonation tanks.

The machinery in the beet-sugar factories operates continuously day and night for a period of approximately 100 days, which period is called by sugar men the "campaign."

There is as much as 17.5 per cent of the weight of the beet produced as sugar; and the factory slicing 100 tons of beets per day for 100 days will produce 17,500 tons of sugar or 350,000 bags of 100 pounds each.

At the end of the campaign the factory is practically disassembled, cleaned, repaired, and reassembled; and this part of the year is called the "inter-campaign." A shut-down of but a few hours during the campaign causes not only loss of production and labor, but also causes a loss due to fermentation of the juices which sometimes amounts to thousands of dollars. For this reason sugar factory drives are generally arranged with as much flexibility of operation as possible and great reliability is essential. Until recently, beet-sugar factories were operated by steam engines driving long line shafts. Lately, a large number of the steam-engine-driven sugar factories are replacing the engine drive with electric drive. As a large quantity of low-pressure steam is required in the cooking process, it is very economical to use steam turbines in the high-pressure mains to act primarily as reducing valves and at the same time to generate electric power for the factory. The sugar factory necessarily requires continuity of service, and the turbine-generator together with the required electric motors have been found to be more reliable than steam-engine drive. Electrification simplifies the operation of sugar-mill machinery. Results obtained in electrified mills show a reduction of 15 to 20 per cent in operating expenses and also show less shut-downs due to mechanical troubles.

Several factories in Southern California have recently changed most of their steam drives to electric drives. Among these are the American Beet Sugar Company's factory, at Chino, which is equipped with both a Steffens plant and a pulp dryer; the Anaheim Sugar Company's factory, at Anaheim, which is equipped with a pulp dryer but no Steffens plant; and the Los Alamitos Sugar Company's factory, at Los Alamitos, which is equipped with a Steffens plant but no pulp dryer. For operating electrically they have installed steam turbines operating under a pressure of approximately 125 pounds gauge with a back pressure varying from 12 to 14 pounds gauge. These factories have also installed a considerable number of electric motors, some of which are shown in the illustrations of this article. For all of the motor drives, with the exception of the sugar centrifugals, squirrel-cage motors have proved entirely satisfactory. On the sugar centrifugals the squirrel-cage motors would prove satisfactory for group drive except for the facts that the motors are so large, in comparison with the generator capacity, and the white-sugar centrifugals are stopped and started so often during the day that in order to obtain the best voltage regulation use is made of slip-ring motors.

A sugar factory slicing 1000 tons of beets each 24 hours requires approximately 800 horse power of motors without a Steffens plant which requires 250 horse power, or a pulp dryer which requires 300 horse power. The load-factor during the campaign, not including auxiliaries, is about 80 per cent.

The Voltage Regulator and Phase-balancer Regulator Equipment of the Philadelphia Electric Company

By R. M. Carothers

Voltage Regulator Engineering Department, General Electric Company

The equipment described in this article was installed to distribute over the three phases of the generators a heavy single-phase railway load. The boosters with their independent exciters maintain constant voltage on the phase from which the railway load is taken, and the shunt phase converter distributes the load to the other two phases and maintains the voltages of these phases equal to that of the first. The single phase railway load at times reaches the value of 24,000 kv-a., and the manner in which this load is smoothed out is shown by a chart from the recording voltmeter. Photographs of the indicating wattmeters and ammeters show also how nicely the phase converter adjusts the load between the three phases.—Editor.

In previous issues of the G-E Review* there have appeared articles dealing with the subject of phase balancers for polyphase circuits in general, and referring to the particular equipment installed at the Philadelphia Electric Company. It was pointed out

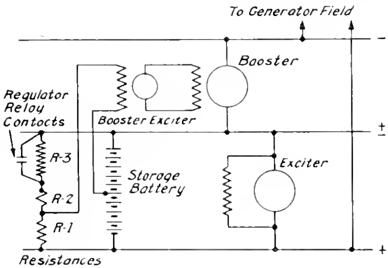


Fig. 1. Elementary Wiring Diagram of Voltage and Phase-balancer Regulator System

that a shunt phase converter requires some type of balancing regulator to cause the converter to correct for any unbalancing effect. As an automatic regulator is therefore absolutely essential to a successful installation of this type of converter, it is deemed advisable at this time to describe the balancing regulator developed especially for this type of service.

There are installed in the plant of the Philadelphia Electric Company both booster voltage regulators and phase-balancer regulators; consequently this article will deal with the booster regulating system (commonly known as the KR system) and the balancing system as a whole, for they both work in conjunction with one common aim in view, that is, to maintain a constant bus bar voltage on all three phases of the system.

The Company possessed standard voltage regulators (that is, the type operating directly upon the exciter field rheostats), but when it became known that a heavy single-phase railway load would have to be supplied it was decided to install the booster system for maintaining constant voltage on the phase from which the railway load would be taken, and

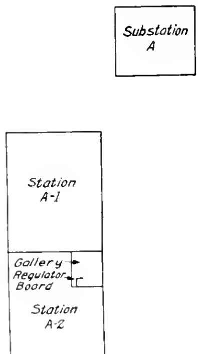


Fig 2. Relative Location of Stations, Philadelphia Electric Company

shunt-phase converters for maintaining the voltage on the remaining two phases equal to that of the first.

The main consideration that led to the adoption of the booster system was the desire to maintain the exciter bus voltage at a con-

* "Single-phase Power Production," by E. F. W. Alexanderson and G. H. Hill, General Electric Review, Dec., 1916, p. 1097.
"Synchronous-phase Converters," by E. S. Henningsen, General Electric Review, June, 1917, p. 479.

stant value, in order that a storage battery might be floated across this bus, thus assuring emergency excitation in case of the failure of any of the exciters. (It is impossible to operate a storage battery in parallel with exciters when the regulator is operating directly upon the exciter fields, due to the variation in the main exciter voltage.) As the principles of the booster system are fairly well known, only a brief description of the system will be given.

Fig. 1 shows this system in simplified form. It consists principally of the main exciters; a booster, the voltage of which depends upon the excitation required at the alternator fields and whose current capacity must equal the sum of the full-load excitation values of the total number of generators to be excited; a separate exciter for this booster; and a set of resistances *R-1*, *R-2*, and *R-3*, the field of the booster exciter being excited from taps on an intermediate point on these resistances and the mid-point of the storage battery. The regulator relay contacts operate across resistance *R-3*. When *R-3* is short circuited, *R-1* being greater than *R-2*, the direction of current in the exciter field will be in one direction; whereas, when the regulator contacts are open and *R-3* is in circuit, this resistance plus *R-2* being greater than *R-1*, the direction of the current in the exciter field will be in the opposite direction. Therefore, the voltage of the main booster can be maintained at any value between maximum buck and maximum boost conditions by the action of the regulator contacts. Assuming the voltage of the exciters to be 250 and the range required across the generator fields to be from 200 to 300, the booster would be designed for 50 volts; and the total voltage across the fields would therefore be from 200 volts (250 − 50) to 300 volts (250 + 50).

Fig. 3 shows how this equipment was installed to conform with the lay-out of the Philadelphia Electric Company's system. There are two voltage regulators installed, each being of the automatic type and having 24 sets of relay contacts. One regulator acts as a spare to the other. It will be noted that the system possesses two main exciter buses, one a 250-volt bus and the other a 125-volt bus; and it will also be noticed that the booster or excitation buses are divided into three sections, one section for Station *A-1*, one section for Station *A-2*, and one section for Substation *A*. The relative location of the different stations, *A-1*, *A-2*, and *A* are shown in Fig. 2.

The generating equipment for Station *A-1* consists of two 15,000-kw. generators while

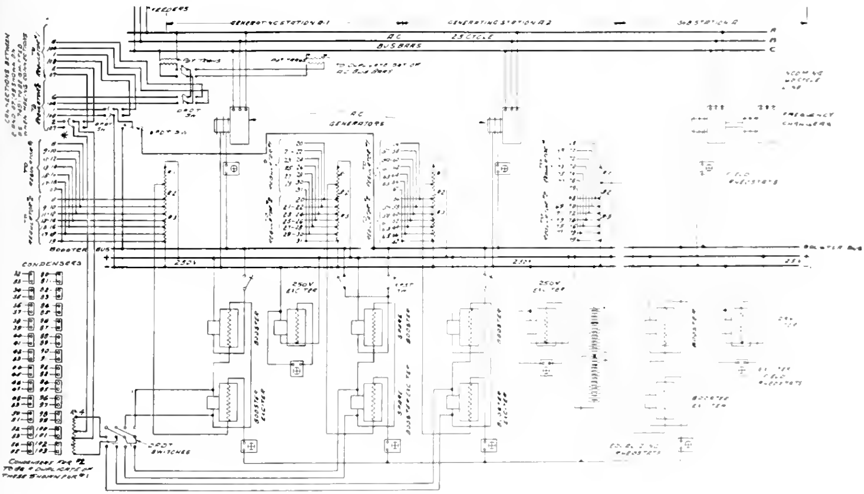


Fig. 3. Complete Wiring Diagram of Regulator System

that for Station *A-2* consists of one 30,000-kw. generator, and one 20,000-kw. generator. The equipment in Substation *A* consists of two 6000-kw and one 4500-kw. units. The boosters for Stations *A-1* and *A-2*, and also the spare booster for these stations, are

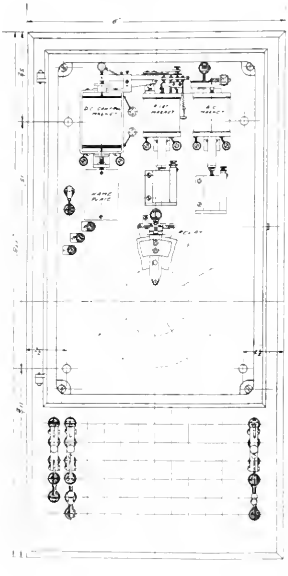


Fig. 4. Phase-balancer Regulator

50-kw., 75-volt machines, while the rating of the booster for the 125-volt bus in Substation *A* is 50-kw. at 50 volts. These boosters are all induction-motor driven and each is supplied with a separate 4-kw., 220-volt exciter which is also induction-motor driven. Although the three excitation buses are independent of each other, they are all controlled from one regulator; the direct-current control for the regulator is taken from either one of the 250-volt sources or the 125-volt source. Equalization of power-factor is obtained and circulating currents prevented by means of different adjustments on resistance *R-3*.

As before stated, the adoption of the shunt type of converter led to the development of the phase-balancer regulator. This regulator, Fig. 4, is similar in every detail to the standard voltage regulator with the exception that it is equipped with an additional pilot or balancing magnet, the core of which is attached to the opposite end of the main alternating-current magnet lever. The elementary connections for this regulator are shown in Fig. 5, where it will be noted that the booster of the balancer set, or converter, is equipped with two sets of field windings the currents of which are at right angles to each other in electrical phase position. Each of these fields, therefore, is excited from a separate exciter and the balancer regulator controls the voltage of each. In order to obtain a wide range of balancing effect, it was desired to reverse the excitation upon these fields, this value being from 125 volts in one direction to 125 volts in the other. To secure this range it was necessary to apply the KR principle for exciting them. The direction of excitation therefore is the resultant of the two field values as shown in Fig. 6.

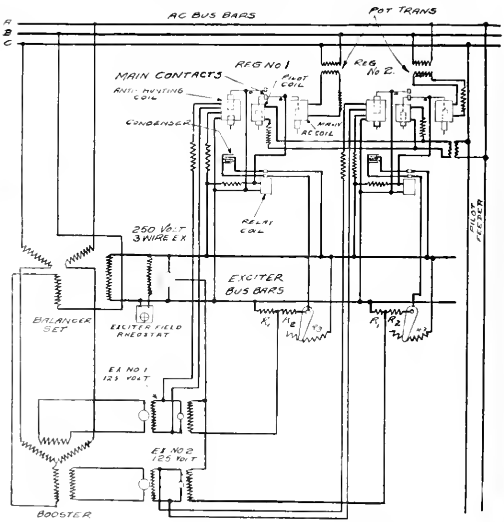


Fig. 5 Connections of Phase-balancer Regulator

Due to the fact that each of these values can be maintained either side of zero, the desired direction and value of excitation can be made to revolve through an angle of 360 deg. At any one instant the voltage will be low on some phases and high on others, which means that the low phases will "motor," and the high phases will generate. In actual operation, the phase converter in order to balance the voltages of the system will take power from the phase or phases upon which the voltage

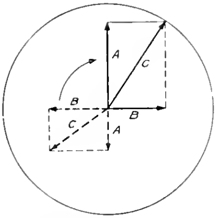


Fig. 6. Vector Diagram Showing Relationship of Two Fields of Booster

is high and will deliver power to the phase or phases of which the voltage is low.

For any one system there are required two balancer regulators, the pilot coils of which are connected in parallel across the phase from which the single-phase load is taken (phase *A-C*, Fig. 5). The main alternating-current magnet coil of one regulator is connected across one of the remaining phases (phase *B-C*), and by means of the pilot coil maintains this voltage equal to that of phase *A-C*. The main alternating-current magnet coil of the remaining regulator is connected across the third phase (phase *A-B*), and by means of its pilot coil maintains the voltage across this phase equal to that of phase *A-C*. As the booster regulator is connected to phase *A-C* a constant as well as balanced voltage is held on all three phases of the system.

The equipment as installed at the Philadelphia Electric Company consists of two balancer sets, each balancing regulator being so constructed that it controls these two sets in parallel. Similar to the boosting regulating equipment there is one set of spare regulators, making a total of four balancer regulators installed.

The generating Stations *A-1*, *A-2*, and Substation *A* were not primarily laid out for such an extensive regulating equipment, and it was therefore quite a problem to find convenient and suitable locations for the regulators and the various boosters and exciters going to make up the total equipment. The difficulty was finally overcome by building in one corner of the operating gallery of Station *A-2* a small switchboard, Fig. 7, to receive the voltage regulators themselves. Fig. 8 shows the rear

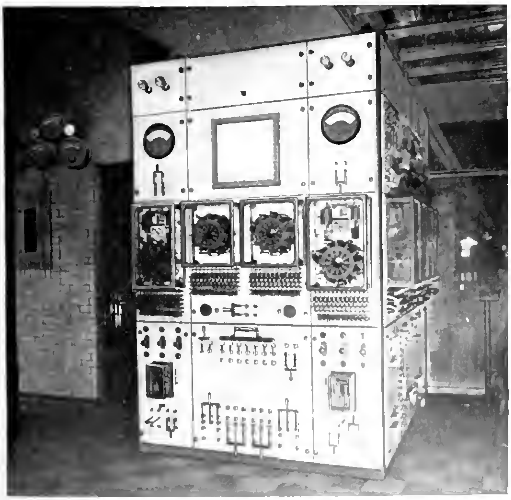


Fig. 7 Voltage and Phase-balancer Regulator Switchboard

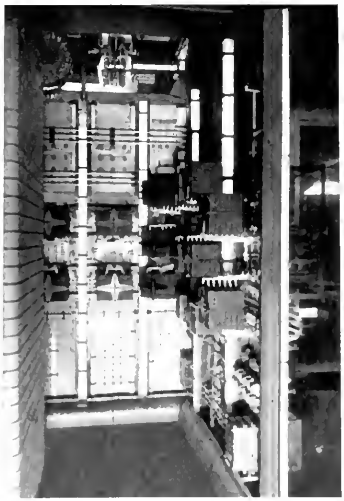


Fig. 8. Rear of Regulator Switchboard

of this board. The boosters and their exciters were located in the high-tension switch gallery just below the main operating gallery, Fig. 9, and the various resistances and rheostats were mounted in the high-tension bus gallery just above the main operating room.

There are no charts available showing what the balancer regulators are accomplishing on the remaining two phases, but a study of the meter readings in Figs. 7 and 11 are of interest, although the readings were taken at a time of day when the load was not heavy and when

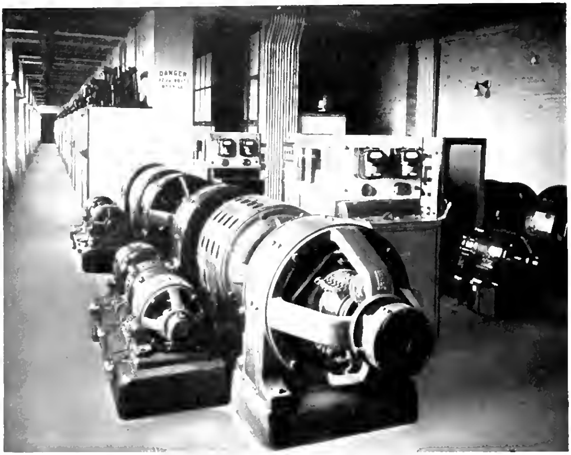


Fig. 9. Boosters and Exciters of Regulator System

It has been pointed out that the total capacity of the three stations amounts to over 100,000 kw. (that is, the equipment connected to the 25-cycle bus). The single-phase railway load is taken from the 25-cycle bus, the peak load at times reaching the value of 24,000 kv-a. Fig. 10 shows the effect of these swings on the system, both with and without the booster regulating equipment in service; and the difference between these two curves readily shows the great improvement caused by the use of the regulator. This improvement is all the more remarkable when the complexity of the regulating equipment is taken into consideration, and when it is further understood that this regulation is being accomplished during the period of peak load and when the railway load swings are the largest and most violent.

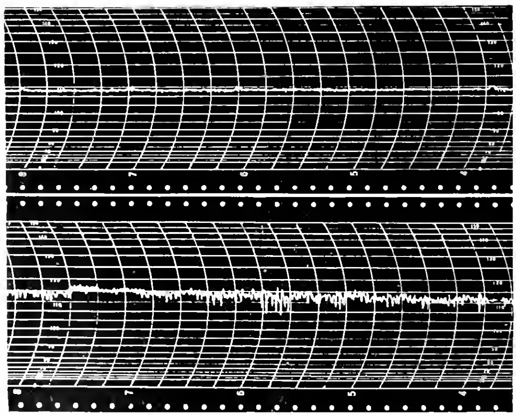


Fig. 10. Effect of Single-phase Railway Load on Voltage of System. Lower curve, without booster regulator; upper curve, with booster regulator

only one of the converter sets was in operation. The three meters in Fig. 7 indicate the voltage of the respective phases of the 25-cycle bus, and it will be noted that the reading of each is approximately the same. Referring to the three wattmeters for converter No. 2, Fig. 11, it will be noted that the top and bottom meter are registering on the same side of zero, while the middle meter is registering on the opposite side. These three meters indicate the kw. load upon each phase of the converter and from their readings it would be inferred that the center meter is registering on the phase from which the railway load is being taken. It will also be noted that the reading of this meter is approximately 1000 kw., while the sum of the readings of the other two meters equals (but in the opposite direction) practically this same amount, which further indicates that the converter set is converting to the extent of 1000 kw.

This regulating and balancing equipment has been in operation a little over a year and the performance of each has been more than satisfactory.

The operation fully demonstrates that an automatic voltage regulator has been designed and developed that will operate satisfactorily on a shunt phase converter, and that will correct quickly for any unbalanced load conditions without any tendency toward hunting of the regulators themselves, or between the converters and the main generating system.

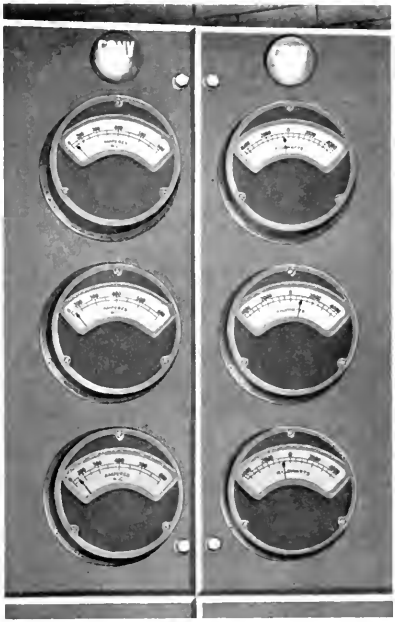


Fig. 11. Indicating Meters Connected in Balancer Circuit. Converter Set Balancing to Extent of 1000 kw.

The 20,000-kw. generator in Station *A-1* is a recent addition to the system and will be supplied with a separate excitation bus, thus making it necessary to increase the size of each voltage regulator 50 per cent. The regulators then will control four separate and independent exciter buses instead of three as has been described in this article.

Life in a Large Manufacturing Plant

PART VII. DEPARTMENTAL SCHOOLS AND GENERAL EDUCATIONAL FACILITIES

By Chas. M. Ripley

Publication Bureau, General Electric Company

The apprentice system described in our January issue trains young men for positions as machinists, pattern-makers, moulders, etc. These workmen are not directly concerned with the electrical characteristics of the apparatus on which they are working, but mainly with the mechanical features—accurate machining, correct dimensions, and a knowledge of the materials with which they work. On the other hand, the students in the departmental schools described in this issue are instructed principally in the design and electrical characteristics of the Company's product. Both courses involve classroom work in theory and application. These two schools, of course, were organized for the purpose of training young men to perform the exacting work demanded in the manufacture of electrical apparatus, and are mutually beneficial to the Company and the student. But in addition to these educational courses there are other schools provided for Company employees, in which instruction in purely academic subjects may be had. Our big industrials realize that the better informed their employees are the more valuable workmen they make, and hence are willing to provide the broadest educational facilities.—Editor.

In the preceding chapter was described the Apprentice Course of the General Electric Company for boys of sixteen years and older having only a grammar school education. In the chapter following this, which will appear in the April General Electric Review, a complete description will be given of the Student Engineers' Course for technical college graduates. But between the elementary apprentice course and the advanced student engineers' course there exists an intermediate field in which are many educational facilities, some of them novel and all of them important. This chapter outlines the various departmental, vocational, and night schools, and the college courses, lectures, publications and libraries constituting these intermediate or miscellaneous educational facilities that are open to employees of the General Electric Company.

That the school facilities are being utilized is evidenced by the record of the number of students registered in Schenectady during the school year 1917–18.

Testing Department Schools	65
Switchboard Department Schools	49
Evening Vocational Schools	318
Municipal Night Schools	877
Union College Evening Classes	142
Comptometer School	30
Total	1481

DEPARTMENTAL SCHOOLS

To boys from eighteen to twenty years of age who have a high school education or equivalent training, but who are unable to go to college, the General Electric Company offers two specialized educational courses in departmental schools.

TESTING DEPARTMENT SCHOOL

The largest departmental school is the Testing Department where, at the Schenectady Works, fifty-five boys are now in attendance. In this two-year course boys can earn $1350 while being taught, if they attend regularly and are always on time.

Six months after the students enter the course they are assisting in measuring electricity a thousand times more accurately than a coal dealer weighs coal, a hundred times more accurately than a grocer weighs sugar, and ten times more accurately than a jeweler weighs diamonds. This skill and precision, this familiarity with the tools of the electrical engineer, is the beginning of the boys' electrical education.

It is acquired in the Standardizing Laboratory amid agreeable surroundings.

In this laboratory there are 8,500 electrical instruments of five hundred different types and capacities, and every one is kept accurate within a fraction of one per cent. The students learn how to select the proper instruments for various uses; how to calibrate, adjust, and repair them; how to use them to measure electrical quantities; and during the six months that they are being instructed in this work they are being paid.

Classroom Studies

The course consists partly of work in the shop where the boys are under individual instructors, and partly of classroom instruction of one hour or more each week. These classes include lectures on direct- and alternating-current theory, and instruction in the use of machines and instruments for testing and the slide rule for rapid engineering calculations.

Besides the classes which are attended on the Company's time, the students are urged to attend night school, the Vocational Schools, or the Union College courses, all of which are described later in this chapter. Fifty out of sixty-five of these students attend one or more of the night courses.

The boys spend fifty hours a week in the shops, attend classroom one hour a week, and are paid for fifty-one hours per week. For every week in which their time record is perfect they are paid for fifty-two hours, that is, a bonus of one hour's extra pay.

In addition to these classes held during business hours, the boys are taken on inspection trips through the shops, examinations are held to test their powers of memory, observation, and reasoning, and special care is taken to guide their reading in proper channels and to keep them interested in good literature and engineering books.

For the classroom work there are two instructors, and two instructors each for the work in the shops and in the Standardizing Laboratory.

Shop Training

In the armature department the students are not required to wind armatures or field coils, nor to perform any of the processes of manufacture; they are put here solely to become thoroughly acquainted with the various methods of design, construction, and manufacture in this department.

Attention is invited here to the difference between the apprentice course and this departmental school. While an apprentice is working upon a machine tool as a machinist, these students are studying and testing the winding of armatures, learning the theory of electric motors and dynamos, and are grasping far more knowledge regarding electricity *per se* than the apprentice does in the same length of time. These students test the insulation and measure the resistance of field spools, stator coils, motor rotors, and stators of both alternating- and direct-current machines of various types. This portion of their training is conducted in many different buildings, and there is always some new illustration in the shop of what has previously been discussed in the classroom. This adds interest to the work and assists the students to a clearer comprehension of what electricity will do.

Shop Instructions and Observations

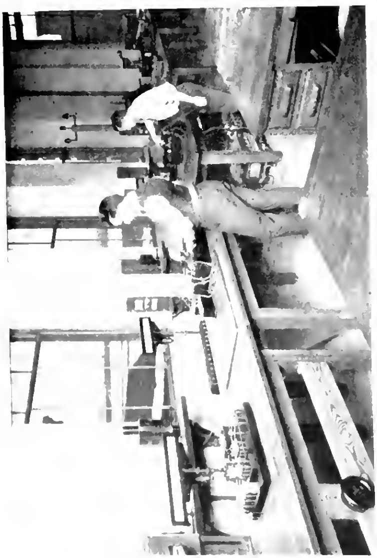
An important feature of this shop training is the method used to train the students' powers of observation, and develop their memory. A few of the examination questions, selected at random from the complete list, are given below. It would be an interesting experiment to find out how many of these questions a college man could answer on the day of his graduation. Each graduate of the Testing Department's school must know how to answer over 100 of these questions correctly, and his knowledge of the subjects is obtained not only in the classroom from text books and blackboard demonstrations, but from the actual operation of the machine itself, supplemented by information imparted to him personally by instructors in the shops.

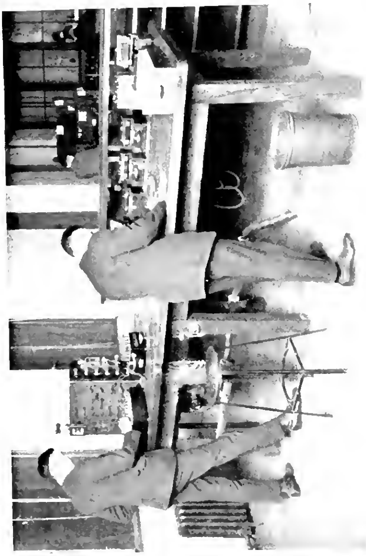
Some Examination Questions Regarding Direct-current Motor Fields

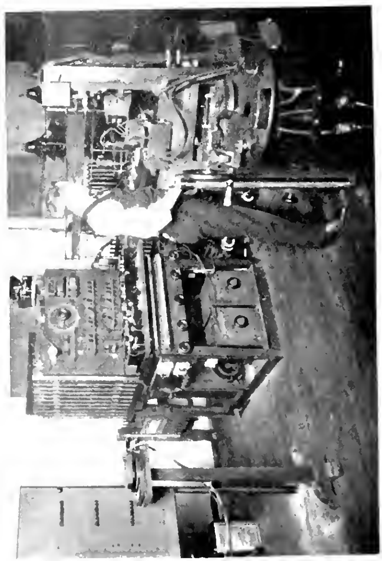
1. What is meant by shunt fields? Series fields? Interpole fields? Compensated fields? Accumulative fields? Differential fields?
2. What is a ventilated field spool?
3. Why are cast iron, cast steel, or laminated structure used in different frames?
4. Why are shims used between pole pieces and frames?
5. Why is a pole piece usually of laminated iron?
6. Why does it have tips on each end?
7. Why are some pole tips perforated?
8. How are shunt spools wound?
9. What is a random wound coil?
10. Which is best, random or layer wound, and why?

Some Examination Questions Regarding Armatures and Commutators

1. What kind of material is used in armature cores?
2. Why is it not solid casting or forging?
3. How is the core assembled? What operations are necessary before ready to receive coils?
4. Why do some armatures have spider construction?
5. Why are holes or ducts provided. At what peripheral speed do armatures run?
6. What is an equalizer?
7. When are wire wound coils used? and when bar?
8. How are the coils formed?
9. What insulation is used on 125-250 volts and how?
10. What insulation is used on 1200-2400-3000 volts d-c.?


1. Learning to Use Delicate Electrical Instruments


2. Calibrating Ammeters and Voltmeters


3. Measuring Magnetic Qualities of Iron Samples


4. Commercial Test of Direct-current Machines

11. What is a shell bound commutator?
12. What is an arch bound commutator?
13. Which is best construction and why?
14. Why is copper used?
15. Why built up of segments?
16. Why not build it of steel or iron?
17. How thick is side mica in commutators?
18. What kind of mica is used?
19. How is side mica prepared?
20. How are cones prepared?
21. How are commutators finally finished?
22. Which is better, turning or grinding?
23. How is a slow-speed armature balanced?
24. How is a high-speed armature balanced?
25. What is the reason for vanes on commutators? How much value?

These questions only suggest how the boys can make the most of their opportunities for obtaining knowledge of electrical designing and contruction details. It is expected that they will become familiar with the kinds of material used, and how these are made up ready for assembly. They are encouraged to learn how the materials are treated and why, how they are assembled in motors, generators, and synchronous converters. The students must be familiar with the forming of armature and field coils; they must know how these are taped, insulated and assembled in the machines, and how the machines are connected up with the electrical circuits from the power stations.

All these questions are practical, and the boys are provided ample time and opportunity—one might say as privileged characters—to ask any questions they desire on how machines are constructed and why.

"Shooting Trouble"

The technical term for discovering defects is "shooting trouble." A trouble shooter is a valuable man in an engineering organization, be it a telephone, lighting, or traction company, or a large industrial plant. A prominent commercial engineer once gained an important customer for his Company because he was able to discover why some of the factory machinery would not work, and pointed out to the operating man the slight readjustment that would restore the machinery to full operation. There is no telling when an intimate knowledge of the interior construction and working of elecfrical machinery will solve some problem in an emergency and help to establish a man's reputation as a thorough-going electrical expert.

During all this period the classroom shows the "why" of the shopwork, and the shopwork shows the utility of the classroom theory. For this shopwork on armatures, motors, commutators, fields, etc., a year is considered sufficient.

Safeguarding Electrical Machinery

The remaining six months of the course are spent partly in testing safeguarding devices which automatically cut off the electric power from machinery that is overloaded or badly handled, and partly in the switchboard department learning how electricity is distributed and controlled. Our engineers harness the waterfalls and make them generate electricity; but it is then necessary for other engineers to harness the electricity so that it can be transformed, transmitted, distributed and controlled to work in the service of mankind.

Another feature of the classroom work is the explanation of the workings of electric circuits. The boys are taught how direct and alternating current passes through the wires; how electricity may be sent in one direction to one machine where it will do one duty; and how, by the mere turning of a switch, it can be sent hundreds of miles in another direction to do duty on another kind of machine. Thus the boys obtain what may be called a practical working knowledge of electricity and electrical machines, and the general principles of safeguarding and controlling that wonderful power with which we can accomplish so much for mankind.

High Voltage Work

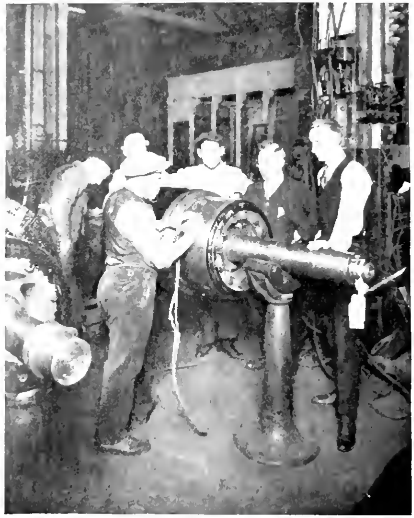
In testing insulation pressures as high as 100,000 volts are finally employed by these boys, and the safety precautions connected with this work are thoroughly learned through personal instruction and experience.

Routine Test

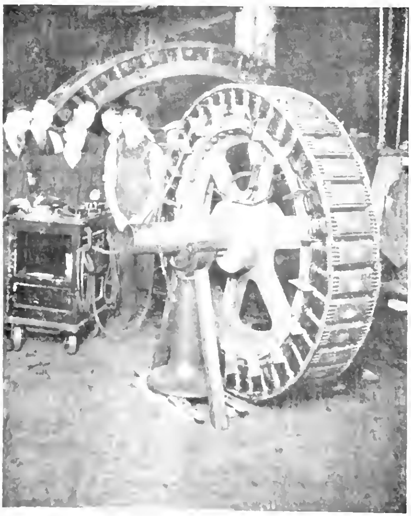
After this two years' course has been completed, the boys are started as routine test men for six months. Regular and prompt attendance during this additional period increases the high school graduate's total earnings to $1,765—all within two and one-half years after his start in the electrical industry!

In the routine test the boys are taught how to wire up machinery to the controllers and the line, and to test such apparatus as compensators and controllers for steel mill motors and mine hoists; how to set up and operate the controlling devices of electric trains, as

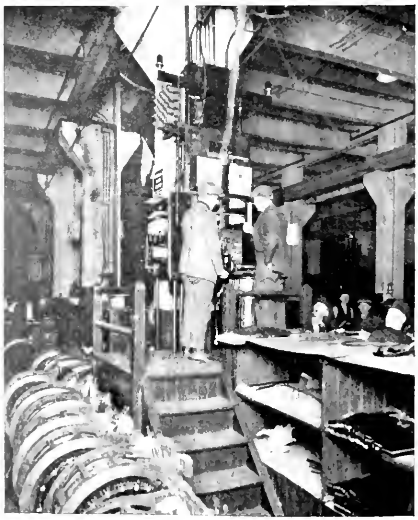
1. Measuring Resistance of Induction Motors



2. Learning How to Test a Motor Armature



3. Instruction in Testing Rotor of Alternator



4. Instruction in High Voltage Work

well as of machines for transforming one kind of electricity into another entirely different kind of electricity. During this advanced six months' course the weekly classroom work is continued as before. The operation of machines is demonstrated in test, and then inspection trips are taken to show the actual performance in service of the motors, controllers, and the various devices which have been studied and tested in the preceding months.

After this schooling, these young men are given a final examination and those who pass become regular test men at increased pay. After an additional year of testing, of a more advanced and expert order, they are then ready for work in the engineering or commercial departments, or for construction on the road, or for engineering or commercial work in the various district offices of the Company in the United States and abroad.

SWITCHBOARD DEPARTMENT SCHOOL

Another school is conducted for the young men of the testing and inspection sections of the switchboard department, and is called the Instruction Course for Switchboard Department Test Men. Those who have been accepted for this course, but who have not actually been graduated from high school, are expected to attend some of the night schools mentioned later in order to get instruction in the indispensable preparatory mathematics.

On January 1, 1918, forty young men were registered in this instruction course. The curriculum is quite rigid and provides for two hours each week of classroom instruction on the Company's time. Every student must prepare the work required and master the subjects given. If a man misses two or more lectures in succession without a satisfactory excuse, he will be automatically dropped from the rolls. If he is absent from four or more classroom sessions during the entire course, he must pass a special examination on the work missed. The engineers in charge of these classes, however, are available an extra hour every week for giving advice, answering questions, and consulting with the students.

In the first six months of classroom work the students are given simple problems teaching the elements and applications of electricity, and the elements of trigonometry. After passing an examination on this work, they enter a second six months' class dealing with problems of electrical measurements, switchboard design and mechanisms, and applications of alternating current.

After passing examination on these subjects the students enter a third class, likewise of six months, and take up the study of switchboard materials, methods of machining, specifications, stocks, business organization, the essentials of economics and the fundamentals of salesmanship. Following graduation from this third class, they are prepared to enter the work of the switchboard department. Any student who after two years has not shown particular aptitude or liking for switchboard work will, on request, be shifted to the routine test in the testing department.

The salaries earned by the students in this course, and the number of hours which they work and attend classes, are identical with the schedule of the Testing Department's preparatory school.

Of course, it is evident that neither of these courses begins to give the equivalent of a college education with its training in advanced mathematics, mechanics, languages, hydraulics, chemistry, and cultural studies; but after having satisfactorily completed the work laid out, these students will have obtained a practical working knowledge of electricity and electrical apparatus, comparably probably to that of a man entering his senior year in the average technical college.

Everything else being equal, the high school graduate with aptitude for mathematics will ultimately be given greater responsibilities and will earn more in the electrical industry than will those who lack the high school training. Although some apprentices, exceptional men, have made extraordinary headway, the average high school man will fare better than the average apprentice. The young men who creditably complete these two courses and continue their studies should rise to positions as designing, construction, and commercial engineers, frequently with apprentice graduates working under their direction. The mathematics which the students obtain in the high school becomes a real asset in future years.

To sum up: The young men learn to handle expertly a great variety of electrical instruments and apparatus, and understand their applications in industry; they learn in classes the theory of electricity; and at all times they are in touch with a great organization where they gain first hand knowledge of mechanical and electrical engineering and manufacturing processes.

Other classes for high school graduates are conducted in the Lynn, Erie, Fort Wayne, and Pittsfield Works. Young men with a complete high school education who have an aptitude for technical work, may obtain training which will fit them to become competent electrical and steam turbine testers, manufacturing and electrical engineers, or cost accountants. The classroom education is of an advanced character, and deals with advanced algebra, plane trigonometry, analytic geometry, mechanics and mechanisms, mechanics of material, magnetism and electricity, machine and dynamo design, heat and heat engines, chemistry and metallurgy, mechanical drawing, and business English.

After a two months' trial period, during which they receive regular compensation, those students are selected who have the requisite characteristics.

Training courses for electrical test men, technical clerks and cost accountants require three years, and afford extended experience in assembling various classes of apparatus. Where practicable, a short assignment in the cost and production departments is included.

These courses are maintained to train young men for efficient service in the various branches of the Company's complex activities, or in power and lighting stations, transportation companies, and other industrial establishments using electrical machinery and steam apparatus; or for those desiring to learn the business of installing and erecting electrical and steam machinery.

The advantage of these courses is that they cover a gap which formerly existed between the apprentice course and the test course given to technical college graduates.

WOMEN TECHNICAL ASSISTANTS

A decided innovation brought about by the war is the school conducted by the Switchboard Sales Department for training young women college graduates for commercial and semi-technical careers in the electrical industry.

Class Room Work

This course opens with a three months' probation period during which the young women are given one hour each day of classroom instruction dealing with apparatus, theory, and business.

In the apparatus classes the devices used on switchboards are brought into the classroom for inspection and are thoroughly described and discussed. The students are also taken on trips through the factory or through neighboring power plants where they can see how the switchboard apparatus protects the big machines and controls its generation and distribution. Inspection trips are taken to afford perspective. For instance, one trip was taken to a waterfall outside of the city, in order to see the power plant which harnesses the waterfall, and the switchboard which dispatches the electric power to the city.

Ample printed matter describing and illustrating the apparatus and installations is available. Lectures are given on the development of switchboards and the applications of air and oil circuit breakers, instruments, transformers, relays, lever switches and fuses. The young women learn the functions of indicating and recording instruments and of other different types of electric meters.

Theoretical Instruction

Lectures are given on how to use the slide rule; classes in elementary electricity alternate with classes describing apparatus. Technical lectures, beginning with the most simple subjects and gradually leading up to more complicated details, explain electrical phenomena and principles. The subjects of some of the lectures are: magnetic action, electromagnetic induction, and the characteristics of motors, generators, transformers, regulators, lightning arresters, etc.

Commercial Class

The young women acquire a knowledge of department organization and routine, how manufacturing costs are obtained, and how to prepare specifications, quotations, and draw up contracts. One hour out of each eight-hour day is spent in classrooms and the other seven hours are spent in commercial engineering work.

In the earlier periods of the course they are taught the uses of the price books, cost advices, and cost issues; they correct these books and keep them up to date, and thus become familiar with the terms and relative values of the items entering into switchboard products.

Next they price and check proposals which will later be submitted to customers of the Company through the salesmen in the various district offices. While doing this work the young women act as assistants to expert estimators or proposal engineers, and learn the details of estimating and the cost of building a switchboard far in advance of the actual construction work. Later they make estimates on small standard-unit switchboards and panels for electric hoists and for small power plants. These young women are being trained as commercial engineers—a profession requiring a knowledge of both business and engineering.

Young women college graduates should have a liking for mathematics, physics or chemistry in order to succeed in this course or in the work of the Research Laboratory or the Testing Laboratory, where other young women graduates are now employed.

Training Girls at Lynn

At the Lynn Works girls have been employed for some time in the construction of small electric motors. Their work requires dexterity in processes of winding and inserting coils in motors. But now girls are being taught to test these motors in order to determine their electrical characteristics and the perfection of their manufacture and operation. This involves a knowledge of electricity, both alternating and direct current, and the engineers of the Company are giving these girls personal instruction in this work.

Comptometer School

A class for instruction in the operation of comptometers is maintained in the Schenectady Works. This class of thirty girl employees meets four evenings a week between 5 p.m. and 7 p.m. For the ambitious girls who are undertaking this work the Company provides an instructor and serves supper each evening on which the class meets.

GENERAL EDUCATIONAL FACILITIES

VOCATIONAL SCHOOLS

The vocational schools offer schooling in General Electric methods. They are open to all with a good education. The vocational schools at Schenectady are conducted inside the Works, are exclusively for employees, and convene immediately after the close of the working day. They are under the joint jurisdiction of the Company and the City Board of Education. The tuition and use of the books cost nothing if the students attend 80 per cent of the sessions.

The courses of study offered in the Schenectady vocational schools are as follows:

Business Arithmetic	Accountancy and Business Administration
English	Touch Typewriting
Commercial Law	Stenography
Elementary Bookkeeping	Phonograph Dictation
Short Course in Accountancy	

Last year 217 students enrolled, of whom 27 were girls. That the students meant business is shown by the fact that two-thirds of last year's students attended 80 per cent or more of the sessions, and 90 students satisfactorily passed in the subjects studied. The average age of the students registered was 25 years, although the minimum age limit is 16 years. Nine courses were offered in 1917–1918, and a total of 318 employees enrolled.

Further information relative to these courses—the subjects treated, books furnished, time and grade required—is given in a twelve-page booklet published annually ** (MU-286).

The Fort Wayne Works have almost parallel courses in their evening classes, and in addition have courses in factory routine and in English exclusively for girls. The Indiana University has an extension at Fort Wayne, so that any employee who desires can take a course in mathematics, economics, foreign languages, and advanced English.

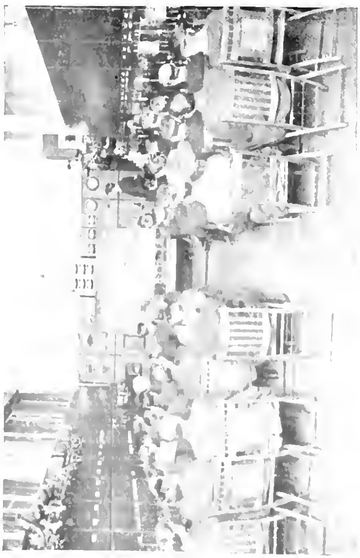
MUNICIPAL NIGHT SCHOOLS

Still other classes, to all of which General Electric employees are eligible, are held in the evening at three Schenectady schools and at the High School. Tuition and use of books in all of these courses are free of charge to all students. Partly because of encouragement from the Company, 877 employees enrolled—two-thirds of some of the classes being composed of General Electric employees.

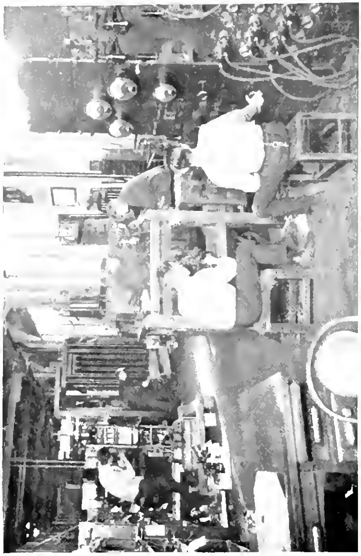
The elementary courses are for boys between the ages of 14 and 16 years who, under the Compulsory Education School law, must attend fifty nights a year. English, spelling, civics, history, and arithmetic are studied here.

The High School classes are held two to four nights a week and provide the following courses:

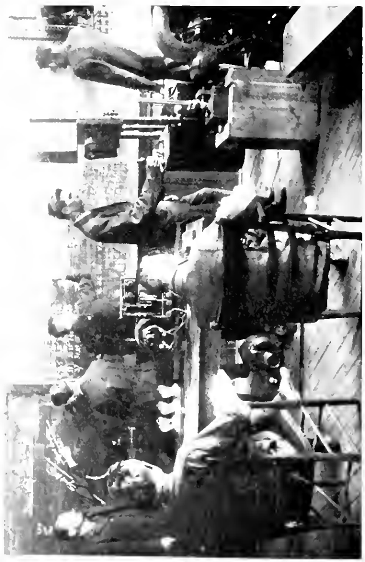
Spanish	Mechanical Drawing
French	Architectural Drawing
German	Shop Mathematics
Algebra	United States History
Plane and Solid Geometry	
Trigonometry	(For girls only):
Mechanics	Cooking
Applied Electricity	Dressmaking
Electrical Engineering	Millinery
Chemistry	Physical Training



1. Switchboard Department Lecture



2. Testing Switchboard Circuit Breakers and Relays



3. Electrical Instruction at Pittsfield Works

4. Evening Electrical Class at Pittsfield Works

Also at the High School there is a three-year commercial course, meeting four evenings a week, which is the equal of the average night business college, and covers bookkeeping, business arithmetic, English, business writing, shorthand, and typewriting.

COLLEGE COURSES

Union College

In the 1917–18 college year, 85 per cent of the total number of evening students were General Electric employees, 142 having enrolled.

Students are here afforded the opportunity of sitting under instructors and professors in a real college atmosphere to study higher mathematics, physics, chemistry, elementary electricity, electrical engineering, Spanish, French, and advanced English.

The Company refunds half of the tuition fees of those employees whose attendance record is 80 per cent.

Union College, established in 1795, is rich in traditions, and its standing among universities is of the highest order. The following prominent men are included in its list of students during past years:

GRADUATES OF UNION COLLEGE

Squire Whipple, Pioneer in the science of stresses. See Engineering News Record, June 21, 1917.

Lewis H. Morgan, Father of American ethnology.

James C. Duane, Chief Engineer in the Army of the Potomac; President Croton Aqueduct Commission.

Charles A. Joy, Founder of Chemistry Dept., Union College; Prof. of Chemistry, Columbia; Editor and Author.

George W. Hough, Astronomer; Director of Dearborn Observatory; Prof. of Astronomy, University of Chicago; Author.

Seaman A. Knapp, Educator in the field of agriculture; Organizer of the Southern Corn Clubs. Introduced upland rice cultivation in U. S., etc.

A. Anastay Julien, Prof. of Biology and Microscopy, Col. of School of Mine; Mich. Geological Survey; North Carolina Geological Survey; Author.

Warner Miller, Introduced the manufacture of wood pulp paper in United States.

George Westinghouse, Inventor of the air brake, etc.

Franklin H. Giddings, Prof. of Sociology, Columbia University; Author.

John C. Spencer, Secretary of War; Secretary of Treasury.

Gideon Hawley, Organizer of N. Y. State school system.

Sidney Breeze, U. S. Senate; Chief Justice, Supreme Court of Illinois.

William H. Seward, Governor of N. Y.; U. S. Senate; Secretary of State.

Henry P. Tappin, President of University of Michigan; Organized present plan of State Universities.

Robert Toombs, U. S. Senate, eight years; Secretary of State, C.S.A.; Brigadier-General, C.S.A.

John Bigelow, Minister to France; Editor and Author.

Alexander H. Rice; Mayor of Boston; Member of Congress; Governor of Massachusetts

Chester A. Arthur, President of United States.

David Murray, Organizer of educational system of Japan.

Attractive booklets describing these Union College Courses are published annually by the General Electric Company and circulated among the employees. The present issue is Y-1065.

University Extension Course at Lynn

At the Lynn Works a university extension course is conducted under the direction of the Massachusetts State Board of Education. The Company encourages the employees to enroll in these courses, which are advertised within the Works. The subjects offered are practical electricity, practical applied mathematics, commercial correspondence, and gas and oil engines.

Evening classes are conducted at the Massachusetts Institute of Technology, Boston University and Wentworth Institute and other schools in Boston, which are attended by employees of the General Electric Works at Lynn, seventeen miles distant.

Evening Work at Pittsfield

The Pittsfield Works conducts a series of evening classes attended by over one hundred employees. They embrace instruction in algebra, geometry, elementary drawing, advanced electricity, advanced mathematics, advanced drawing, jig and tool design, elementary electricity, mechanics, English, and a course in Spanish.

Advanced Electricity at Pittsfield

From the class in advanced electricity the past year, two men were promoted to testing work—work formerly done by college men—and a third man from the evening classes was selected as an assistant to the head of the educational department.

It will be noted from the accompanying photographs that the equipment provided for the students' laboratory work is similar to that used in the regular laboratory and in testing work. Some trigonometry, analytical geometry and the first principles of calculus are taught in the advanced electricity course; and altogether a very good

1. Studying Illumination at Pittsfield Works

2. Mechanical Drawing Class

3. Research Laboratory Library at Schenectady

4. A Corner in the Main Scheoectady Library

idea of alternating current theory is obtained.

As an illustration: In the Engineering Department is a young man who in three years' time has passed from office boy to junior engineer. During this time he moved about from position to position in the shop, where he engaged in regular factory operations and at the same time took advantage of all the evening classes in electricity and mathematics.

At present over 100 students are enrolled in the evening technical classes—in fact, about the same number of students as are enrolled in the apprentice courses. A fee of $5 is charged for these classes, but the fee is refunded with a passing mark of 75 per cent.

LECTURES

Departmental Lectures

Primarily for their technical and commercial educational value, the departmental lecture system was introduced in the various factories and district office; and a happy byproduct of these lectures has been their effect on the *esprit de corps*. Many of these lectures are of such importance and value that they are reprinted for the confidential information of the General Electric engineers and the commercial men throughout the world. Department managers, section heads, and prominent men from other departments deliver these lectures.

The attendance at the Switchboard Departments' lectures is drawn from the designing, requisition, commercial and production divisions of the office force, and from the foremen and assistant foremen of the factory force. The lectures describe the details of the Company's organization, the relation of the Switchboard Department to the organization, and the manufacture, application, and operation of the equipment manufactured by the Department or controlled by switchboards.

Lectures on strictly engineering subjects are delivered once a week for six months to the newly employed engineers, most of whom are college graduates and have been through the test course.

All members of the Power and Mining Engineering Department are expected to attend the weekly lectures of the Department, which cover such subjects as production, patents, advertising, sugar mills, voltage regulators, transformers, rotary converters, lightning arresters, high tension bushings, and electric furnaces.

The Research Laboratory lecture is held weekly through the winter. It is intended primarily for employees of the Department, but other employees are welcome. The purpose of the lectures is to acquaint all members of the laboratory with what is being done in the field of research, both within and without the laboratory. They embrace such subjects as: The Second Law of Thermodynamics; The Theory of Heteogeneous Reactions; Spectrum Series; Over-voltage; Radium Work of the Bureau of Mines; Research Work at Badische, Germany; Magnetic Amplifier for Radiotelephony; Mechanism of Cell Permeability; X-ray and Cancer; X-ray Spectra; Permeability and Cell Life; Constitution of Rubber Molecule; Absolute Zero, Liquefaction of Air and Separation of Constituents; Chemical Reactions at Low Pressures: X-Ray and Crystals; Ionization; Ferro-magnetic Alloys; Physical Chemistry of the Blood; Spectroscopy of Extreme Ultraviolet; Dielectric Phenomena; Luminescence; The Beaver as an Engineer.

The Publication Bureau also has weekly lecture courses for all members of the department, the object of which is to acquaint the members of the Bureau with the activities of the different sections and to consider ways of co-operating with other departments of the Company in the preparation of publications, bulletins, handbooks, technical letters, and all the multiplicity of publications required by a large manufacturing organization such as the General Electric Company. The subjects of some of the recent lectures are:

- Illustrations in Publications and Advertising.
- The Printing Department.
- Making Cuts and Electrotypes.
- The GENERAL ELECTRIC REVIEW.
- Supply Catalogues and How They are Made.
- Handbooks and How Prepared.
- Some Photographic Problems.
- Motion Pictures.

American Institute of Electrical Engineers

Another prominent educational feature in the various cities where large factories of the General Electric Company are situated is the bi-weekly section meeting of the American Institute of Electrical Engineers. The Lynn Section, with over 1600 members, is the largest of the thirty-one sections of this Institute, and the Schenectady Section is second largest, its membership numbering approximately 1200.

Anyone interested in the study, manufacture or application of electrical apparatus and resident in the vicinity, is eligible to membership. The local section is, therefore, open to all factory and office employees of the General Electric Company.

Last year's addresses at the Schenectady Section included the following papers:

- The Electrically Driven Gyroscope and Its Uses.
- Regulation of Public Utilities.
- The Illumination of the Panama-Pacific International Exposition.
- Railway Electrification.
- Paper Industry.
- Electrically Driven Ship Propellers.
- The Engineer at the Battle of Verdun.
- The Art and Science of Illumination.
- Production of Steam from Coal.
- The "Amphibious" Submarine.
- High-speed Electric Locomotives.
- Niagara Power or a Real Coal Shortage.

Other associations which have sections or branches in Schenectady and hold frequent meetings are: The American Society of Mechanical Engineers, The Society of Engineers of Eastern New York, The National Electric Light Association, The Illuminating Engineering Society, The American Chemical Society, and The Edison Club.

PUBLICATIONS

A great variety of publications are available, many of which are for the exclusive use of the employees.

The technical letters are confidential and are not for public distribution.

Instruction books are issued showing how electrical machinery should be shipped; how the foundations should be prepared; how the machines should be assembled and set up in the field; and how all the electrical connections should be made.

Lavishly illustrated bulletins are available in which are described and pictured the thousands of applications of electricity to hundreds of different industries. For example, in the paper and pulp industry, the various uses of electricity are described and illustrated, from the cutting of the logs in the forest to the completion of the roll of paper ready to ship to the newspaper office. The function of the electric motor in cutting, grinding, chipping and beating the wood to a pulp, and changing this watery pulp into finished paper, are interestingly and clearly described.

Throughout all the Works of the General Electric Company are a thousand bulletin boards. Every week a new safety bulletin is posted showing means of preventing accidents and the sad results of carelessness. The safety work of the General Electric Company was described in Part II of this series which deals with the "Prevention of Accidents."

LIBRARIES

Some nations know how to amass wealth, but their economic system is unable to distribute it properly.

Some libraries are storehouses where knowledge is amassed—neatly segregated, indexed, classified, and then merely *stored*. Other libraries not only store knowledge but condense it, fabricate it into convenient forms, do it up in attractive packages, and distribute it to a selected list of "ultimate consumers."

Main Library

The General Electric main library at Schenectady is among the latter class. In fact, this library is a tool of the industry, actually serving the factory, the department heads, research investigators, scientists, commercial, production and accounting departments with the latest news from current periodicals, transactions of scientific and engineering societies, and reviews and translations of books printed in all languages.

It might be said that this library combines the functions of the editorial and circulation departments of a newspaper, for it reads and selects the news, featuring the important points, and then circulates the information to its subscribers. A semi-monthly Library Notice informs all recipients regarding the contents of all new articles and books. In this sense the Library is education plus—it becomes a regular service department as opposed to a place for semi-occasional "little journeys" of an educational nature. In these days of modern business only rare individuals go to the library—pressure of twentieth century life demands that the library be brought to the individual. Or putting it differently, "If the mountain will not come to Mohammed, Mohammed must go to the mountain."

Our modern technical librarian can now give us just what we want, when we want it, in a convenient form and in hundreds of cases without our asking for it. Hence the modern industrial library has ceased to be a thing apart from the business of the plant;

it is no longer a disregarded adjunct. From a storage vault it has become a manufactory, changing the raw material into the accessible finished product.

Research Laboratory Library

Here also the service work is not limited to the mere business of bulletin board notices of new books received, new periodicals on file and current society business and conventions: the accessions are read and digested. In some cases the complete article is sent to, or called to the attention of, interested individuals. Where requested, digests or translations are made and are sent to those engaged in lines of work kindred to the subjects treated in the new books and periodicals. This library has a file of lantern slides showing tabulated data, formulae, photographs or drawings, novel installations and apparatus. These lantern slides can be chosen as needed for lectures.

The up-to-date corporation librarian has the intelligence to select important matter, and the initiative to authorize reprints for distribution within the organization; the authority to approve the appropriation and a knowledge of who would be interested in the subjects treated.

It requires intelligence of a high order to prepare bibliographies of such subjects as the latest developments throughout the world in the nitrogen industries, in X-rays, high explosives or submarines, and separate the wheat from the chaff!

The Library has its commercial aspects as well. The time of high-salaried experts need not be taken up in answering questions when complete and detailed information can be obtained from the specialized librarian. Inquirers do not consume hours of the time of "the man who knows," at $25 a day, when more exhaustive and detailed information can be obtained from books standing idle on their shelves. Modern corporation life has taught us not to ask the librarian for a book on chemistry when we desire information on boronized copper, for we save time by inquiring definitely about boronized copper. If we wish to read a paper on pure electron discharge in radio-telephony, delivered before a society, we ask for that paper and not for the mailing address of the society in New York or Chicago; for the pamphlet is on file and possibly a score of extra copies, for—*mirabile dictu!*—our demand has been anticipated!

These facilities could be elaborated to include the Boston Public Library, only sixteen miles from the West Lynn Works, as the New State Library at Albany, with a capacity of two million volumes, is only seventeen miles from Schenectady. Many other small libraries are omitted, as they are too specialized to be of general interest.

In many respects a similar account could be written of the educational facilities in the other plants of the General Electric Company.

Correspondence Schools

The leading correspondence schools of the country report enrollments of General Electric employees totalling 2000

	Books and Bound Periodicals	Pamphlets	Current Periodicals
Main General Electric Library (Schenectady)	4,000	800	100
General Electric Law Library	4,000		
*Research Laboratory Library	2,775	1,300	90
Testing Laboratory Library	475		10
Power and Mining Department Library	190		
*Illuminating Laboratory Library	450	4,000	20
*Consulting Engineering Laboratory Library	100		2
*Patent Department	2,000	250,000	22
*Publication Bureau Data Section		7,500	
Union College Library	51,000		50
Schenectady Public Library	40,000		158
New York State Library (Albany)	428,000	150,000	
New York Office	350		30
Boston Office	225	75	31

* Partly confidential.

Methods for More Efficiently Utilizing Our Fuel Resources

PART XIV. ADVANTAGES OF HIGH PRESSURE AND SUPERHEAT AS AFFECTING STEAM PLANT EFFICIENCY*

By Eskil Berg

Turbine Engineering Department, General Electric Company

The steam turbine has become the prevailing type of prime mover for power stations and the preferred type for new steamships. Mr. Berg reviews the theoretical possibilities of higher pressures and superheats, as it is mainly by these means (or by the binary vapor principle) that greater operating economy can be secured. It is of interest to add that the principal changes from present practice will be in the design of the boiler rather than in the turbine or the station piping.—Editor.

The use of high steam pressure and superheat is very effective for improving the fuel economy of any steam prime mover, particularly the turbine. The gain will be substantiated both theoretically and practically in the following; but before proceeding with the demonstration a few fundamental points about steam and its action in turbines will be reviewed for the sake of clearness.

The Curtis type of turbine is particularly well suited to take advantage of high steam temperature on account of the large clearances used, and also on account of the fact that the initial high temperature is confined to the steam chest, the temperature being greatly reduced when it reaches the inside of the turbine itself.

Efficiency of a Turbine

The efficiency of a turbine is the ratio of the mechanical energy taken out of the steam by the turbine to the total energy in the supplied steam, when this steam is expanded adiabatically† from the pressure at the throttle valve to the exhaust pressure in the exhaust casing of the turbine.

The steam consumption of a turbine, when connected to an electric generator, is generally stated in pounds of steam per kilowatt-hour, and is the amount of steam required to deliver one kilowatt for one hour.

"Theoretical water-rate" is a term constantly used in all turbine investigations and is the ratio of one kilowatt-hour expressed in foot-pounds (2,654,000) to the available energy of one pound of steam expressed in foot-pounds. The ratio between the theoretical water-rate and the actual measured water-rate, gives the efficiency of the turbine. Table I gives the theoretical water-rates per kilowatt-hour at the steam pressures, superheats, and vacua generally used.

Formula for Calculation of Available Energy

The formula for calculating the available energy of steam expressed in foot-pounds, either dry or superheated, when expanding adiabatically to any back pressure, is seldom found in handbooks or textbooks, and when such formulas are found they are rather complex and difficult to use. The formula can, however, be made very simple when expressed as the difference between the total heat input and the heat left in the liquid together with the latent heat in the mixture at the lower pressure. The formula then becomes:

Available energy in ft. lb. =

$$778\ [H_1 + C_p t_1 - (q_2 + x_2 r_2)]$$

H_1 = Total heat of saturated steam at initial pressure p_1.
C_p = Specific heat of superheated steam.
t_1 = Degrees Fahr. superheat at pressure p_1.
q_2 = Heat of the liquid at lower pressure p_2.
x_2 = Quality of the steam at pressure p_2.
r_2 = Latent heat at pressure p_2.

All of these quantities are found in any steam table except x_2 (dryness factor) which is, however, easily calculated from the fact that the entropy is constant before and after the expansion.

Entropy of superheated steam is:

$$C_p \log_e \frac{T_1 + t_1}{T_1} + \frac{r_1}{T_1} + \phi_1$$

*Presented at the 196th meeting of the Schenectady Section of the A.I.E.E., Schenectady, N. Y., January 24, 1918.

†Adiabatic expansion takes place when the temperature of steam is lowered without abstraction of heat, in other words, all the lowering of temperature is done entirely by work taken out of the steam.

TABLE I

THEORETICAL WATER RATES PER KILOWATT HOUR

(Heat values from Marks & Davis' Steam Tables)

Supht. Deg. F.	26 in.	27 in.	27.5 in.	28 in.	28.5 in.	29 in.	26 in.	27 in.	27.5 in.	28 in.	28.5 in.	29 in.
	150 lb. gauge						160 lb. gauge					
0	11.80	11.23	10.92	10.55	10.12	9.59	11.66	11.10	10.79	10.43	10.01	9.50
25	11.61	11.05	10.74	10.38	9.96	9.44	11.45	10.91	10.61	10.26	9.85	9.34
50	11.42	10.87	10.58	10.22	9.81	9.30	11.28	10.75	10.45	10.11	9.70	9.21
75	11.24	10.71	10.41	10.07	9.66	9.17	11.10	10.58	10.29	9.95	9.56	9.07
100	11.07	10.55	10.26	9.92	9.52	9.03	10.92	10.41	10.13	9.80	9.42	8.94
125	10.90	10.38	10.10	9.77	9.38	8.90	10.75	10.25	9.98	9.66	9.27	8.81
150	10.75	10.23	9.96	9.63	9.25	8.78	10.60	10.10	9.84	9.52	9.15	8.69
	165 lb. gauge						170 lb. gauge					
0	11.57	11.03	10.73	10.37	9.96	9.45	11.50	10.96	10.66	10.32	9.91	9.40
25	11.39	10.84	10.55	10.20	9.80	9.30	11.31	10.78	10.49	10.15	9.75	9.25
50	11.20	10.68	10.39	10.05	9.65	9.16	11.13	10.61	10.33	9.99	9.60	9.11
75	11.02	10.50	10.22	9.89	9.50	9.02	10.95	10.45	10.17	9.84	9.45	8.98
100	10.85	10.35	10.08	9.75	9.37	8.89	10.79	10.29	10.02	9.70	9.32	8.85
125	10.68	10.18	9.92	9.60	9.23	8.76	10.62	10.13	9.86	9.55	9.18	8.73
150	10.52	10.04	9.77	9.46	9.10	8.64	10.47	9.99	9.73	9.42	9.05	8.60
	175 lb. gauge						180 lb. gauge					
0	11.44	10.91	10.61	10.27	9.87	9.36	11.37	10.85	10.56	10.22	9.82	9.31
25	11.25	10.72	10.44	10.10	9.70	9.21	11.18	10.67	10.38	10.05	9.66	9.17
50	11.07	10.55	10.27	9.94	9.55	9.07	11.01	10.50	10.22	9.89	9.51	9.03
75	10.89	10.39	10.11	9.79	9.41	8.94	10.83	10.34	10.06	9.74	9.37	8.90
100	10.72	10.23	9.96	9.64	9.27	8.81	10.66	10.17	9.90	9.60	9.22	8.77
125	10.55	10.07	9.81	9.50	9.13	8.68	10.49	10.02	9.76	9.46	9.09	8.65
150	10.40	9.92	9.67	9.37	9.00	8.56	10.34	9.87	9.61	9.32	8.96	8.52
	185 lb. gauge						190 lb. gauge					
0	11.31	10.79	10.51	10.17	9.77	9.28	11.25	10.74	10.46	10.12	9.73	9.25
25	11.12	10.61	10.33	10.00	9.61	9.13	11.06	10.56	10.28	9.96	9.58	9.10
50	10.94	10.44	10.17	9.84	9.46	8.99	10.88	10.39	10.12	9.80	9.42	8.96
75	10.77	10.28	10.02	9.69	9.32	8.86	10.71	10.23	9.97	9.65	9.28	8.82
100	10.60	10.12	9.86	9.55	9.19	8.73	10.55	10.08	9.82	9.51	9.15	8.70
125	10.43	9.97	9.72	9.41	9.05	8.61	10.39	9.92	9.67	9.37	9.01	8.58
150	10.28	9.82	9.57	9.27	8.92	8.49	10.23	9.77	9.53	9.24	8.88	8.46
	195 lb. gauge						200 lb. gauge					
0	11.20	10.69	10.41	10.08	9.69	9.22	11.15	10.64	10.37	10.04	9.66	9.18
25	11.01	10.51	10.24	9.92	9.53	9.07	10.95	10.46	10.19	9.87	9.49	9.03
50	10.83	10.35	10.08	9.76	9.38	8.92	10.77	10.29	10.03	9.71	9.34	8.88
75	10.66	10.18	9.92	9.61	9.24	8.79	10.61	10.13	9.87	9.57	9.20	8.75
100	10.50	10.03	9.77	9.47	9.11	8.66	10.44	9.97	9.72	9.42	9.06	8.62
125	10.33	9.87	9.62	9.32	8.97	8.54	10.28	9.83	9.58	9.28	8.93	8.50
150	10.18	9.72	9.48	9.18	8.84	8.42	10.13	9.68	9.44	9.15	8.81	8.38
200	9.86	9.43	9.19	8.92	8.59	8.18	9.81	9.39	9.15	8.88	8.55	8.15
	205 lb. gauge						210 lb. gauge					
0	11.09	10.60	10.32	9.99	9.62	9.15	11.04	10.55	10.28	9.97	9.59	9.12
25	10.90	10.41	10.14	9.82	9.45	8.99	10.85	10.37	10.10	9.79	9.42	8.96
50	10.72	10.24	9.98	9.67	9.30	8.85	10.68	10.20	9.94	9.63	9.27	8.82
75	10.55	10.09	9.83	9.52	9.17	8.72	10.50	10.04	9.78	9.48	9.13	8.69
100	10.39	9.93	9.68	9.38	9.03	8.59	10.34	9.89	9.63	9.34	9.00	8.56
125	10.23	9.78	9.54	9.24	8.90	8.47	10.19	9.75	9.49	9.21	8.87	8.44
150	10.08	9.64	9.39	9.11	8.77	8.35	10.03	9.60	9.35	9.07	8.74	8.32
200	9.77	9.35	9.11	8.84	8.52	8.12	9.73	9.31	9.08	8.81	8.49	8.10
	215 lb. gauge						220 lb. gauge					
0	11.00	10.51	10.24	9.93	9.55	9.09	10.95	10.47	10.20	9.89	9.52	9.06
25	10.79	10.32	10.05	9.75	9.38	8.93	10.75	10.28	10.02	9.71	[illegible]	8.90
50	10.62	10.16	9.89	9.59	9.24	8.79	10.58	10.11	9.85	9.55	9.20	8.76
75	10.46	10.00	9.74	9.44	9.09	8.66	10.41	9.95	9.70	9.40	9.06	8.63
100	10.30	9.85	9.60	9.30	8.96	8.53	10.24	9.80	9.55	9.26	8.93	8.50
125	10.14	9.70	9.46	9.16	8.83	8.41	10.09	9.66	9.42	9.13	8.80	8.38
150	9.98	9.55	9.31	9.03	8.71	8.29	9.94	9.52	9.28	9.00	8.67	8.27
200	9.68	9.27	9.04	8.77	8.46	8.06	9.64	9.23	9.00	8.74	8.42	8.03
	225 lb. gauge						230 lb. gauge					
0	10.90	10.42	10.16	9.85	9.48	9.03	10.86	10.39	10.12	9.82	9.45	9.00
25	10.71	10.24	9.98	9.67	9.32	8.87	10.66	10.20	9.94	9.64	9.28	8.84
50	10.53	10.07	9.81	9.52	9.17	8.73	10.48	10.03	9.78	9.48	9.13	8.70
75	10.36	9.91	9.66	9.37	9.03	8.60	10.32	9.87	9.63	9.34	[illegible]	[illegible]
100	10.20	9.76	9.52	9.23	8.90	8.47	10.16	9.72	9.48	9.20	8.86	[illegible]
125	10.05	9.62	9.38	9.10	8.77	8.35	10.01	9.58	9.34	9.06	8.74	[illegible]
150	9.90	9.47	9.24	8.96	8.64	8.23	9.85	9.44	9.20	8.93	8.61	[illegible]
200	9.60	9.20	8.97	8.71	8.40	8.01	9.56	9.16	8.93	8.67	[illegible]	[illegible]
	235 lb. gauge						240 lb. gauge					
0	10.81	10.35	10.01	9.78	9.42	8.96	10.76	10.31	10.05	9.75	[illegible]	[illegible]
25	10.61	10.15	9.90	9.60	9.25	8.81	10.57	10.12	9.86	9.57	[illegible]	8.78
50	10.44	9.99	9.75	9.45	9.10	8.67	10.38	9.95	9.70	9.41	[illegible]	8.64
75	10.27	9.83	9.59	9.30	8.96	8.54	10.23	[illegible]	9.55	[illegible]	[illegible]	[illegible]
100	10.12	9.68	9.45	9.17	8.83	8.42	10.08	9.65	9.41	[illegible]	[illegible]	[illegible]
125	9.96	9.54	9.30	9.03	8.70	8.29	9.92	9.50	9.27	[illegible]	[illegible]	[illegible]
150	9.81	9.40	9.16	8.90	8.58	8.18	[illegible]	[illegible]	[illegible]	8.86	[illegible]	[illegible]
200	9.52	9.12	8.90	8.64	8.33	7.95	9.48	[illegible]	8.87	8.61	[illegible]	[illegible]
	245 lb. gauge						[illegible]					
0	10.73	10.27	10.01	9.71	9.35	8.91	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	10.53	10.08	9.83	9.53	9.18	8.75	10.49	10.04	[illegible]	[illegible]	[illegible]	[illegible]
50	10.35	9.91	9.67	9.38	9.04	8.61	10.31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
75	10.19	9.76	9.52	9.23	8.90	8.48	10.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
100	10.03	9.61	9.37	[illegible]	8.77	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
125	9.88	9.47	9.23	8.96	8.64	8.24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
150	9.73	9.33	9.10	8.83	8.52	8.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
200	9.43	9.04	8.82	8.57	8.27	[illegible]	9.41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Entropy of moist steam is:

$$\frac{X_2\ r_2}{T_2}+\phi_2$$

By making these equal and solving for x_2 there results:

$$x_2=\frac{T_2}{r_2}\ \left(C_p \log_e \frac{T_1+t_1}{T_1}+\frac{r_1}{T_1}+\phi_1-\phi_2\right)$$

T_1 = Absolute temperature at pressure p_1.

T_2 = Absolute temperature at pressure p_2.

ϕ_1 = Entropy of water at pressure p_1.

ϕ_2 = Entropy of water at pressure p_2.

Example: Find the available energy of one pound of steam when expanding from 250-lb. gauge pressure, with 250 degrees superheat, to 29 in. vacuum, (0.5 lb. abs.)

Available energy $=778\ [H_1+C_pt_1-(q_2+xr_2)]$

$H_1=1202.3$

$C_p=0.553$

$t_1=250$

$q_2=48$

$r_2=1046.7$

$$x_2=\frac{T_2}{r_2}\left(C_p\ log_e\ \frac{T_1+t_1}{T_1}+\frac{r_1}{T_1}+\phi_1-\phi_2\right)$$

$T_1=461+406.2=867.2$

$t_1=250$

$r_1=821.6$

$\phi=0.5739$

$r_2=1046.7$

$T_2=461+80=541$

$\phi_2=0.0932$

$$x_2=\frac{541}{1046.7}\left(0.553\ log\ \frac{1117.2}{867.2}+\frac{821.6}{867.2}+0.5739-0.0932\right)$$

$$=\frac{541}{1046.7}\left(0.553\ \times\ 0.2546\ +\ 0.947\ +\ 5739-0.0932\right)$$

$0.5168\times1.5685=0.812$

Dryness factor $=0.812$

Available energy $=$ $778\,[1202.3+0.553\times250-48+0.812\times1046.7)]=778\times444.3=346{,}000$ ft.-lb.

Gain by the Use of High Steam Pressure

The theoretical gain due to the use of high steam pressure is well illustrated in Table II. It will be seen that by going from 200 lb. to only 500 lb. pressure there is a saving in fuel of 14.43 per cent. What this would mean in money may be illustrated by taking as an example a medium size central station burning about 900 tons of coal per day. Operating at 500 lb. pressure would save 130 tons of coal a day, which at $5 a ton would amount to $650, and in a year would mean a saving of perhaps $200,000.

Theoretical Gain by Superheat

The theoretical gain by super-heat is best shown by Table III which is calculated on the basis of an initial steam pressure of 250 lb. gauge expanding to 29 in. vacuum.

Practical Gain by Superheat

In an average well designed turbine of the impulse type, the magnitude of the total losses are made up about as follows when dry initial steam is used:

Loss due to friction in nozzles and blades, and windage loss of disk and blades	20 per cent
Leakage loss	3 per cent
Rejected energy (due to residual steam velocity)	3 per cent
Bearings, packings, etc.	1 per cent
Total losses	27 per cent
Efficiency of turbine	73 per cent

It will be seen that the first item is by far the most important one, and it is this item which is reduced by the use of superheat. The use of 200 degrees superheat will reduce the friction and windage loss about one quarter or to 15 per cent, and the total loss would then be 22 per cent, making the turbine efficiency 78 per cent. This reduction is effected by the superheat reducing the moisture in all the stages. The reduction is best shown by the entropy-temperature diagram, Fig. 1. From this diagram it will be seen that starting with steam initially dry at 265 lb. absolute pressure and expanding it adiabatically to 29 in vacuum, through a turbine of 100 per cent efficiency, would result in steam of about 26.5 per cent moisture; whereas if the steam had been superheated to say 250 degrees this moisture would be reduced to about 19 per cent, a reduction of almost 30 per cent. In an actual turbine this percentage of moisture is of course a great deal lower, depending upon the efficiency.

Fig. 2 shows a cross-section of a turbine having ten stages and gives approximately the condition of the steam in all the stages, assuming the turbine has 80 per cent efficiency is supplied with steam at 250 lb. gauge pressure, 250 degrees superheat, and is exhausting into 29 in vacuum. Table IV gives a comparison of the steam condition in this turbine had the steam been initially dry.

TABLE II

Absolute pressure pounds	Corresponding temperature, deg. F.	Total heat	Increase in total heat, per cent	Available energy in ft.-lb. expanding to 28.5 in. vacuum	Increase of available energy per cent	Net gain in fuel, per cent
200	381.9	1198.5	. . .	272,000	. . .	. . .
300	417.5	1201.9	0.28	293,000	7.72	7.44
400	444.8	1202.5	0.33	304,500	11.95	11.62
500	467.2	1201.7	0.27	312,000	14.7	14.43
600	486.5	1199.8	0.11	319,000	17.2	17.09
700	503.4	1197.4	0.902	323,000	18.7	18.79
800	518.5	1194.4	−0.342	327,000	20.2	20.54
900	532.3	1191.1	−0.617	329,000	20.9	21.51
1000	545.0	1187.6	−0.909	331,000	21.7	22.6

TABLE III

Degree Super-heat	Temp. Degrees F.	Total avail. energy per lb. of steam	Total B.t.u. per pound	Per cent increase in coal to produce superheat	Per cent increase avail. energy due to superheat	Net theoretical gain per cent	Actual gain per cent	Actual net gain per cent
(1)		(2)	(3)	(4)	(5)	(6) = (5−4)	(7)	(8) = (7−4)
0	406	298,000	1202.3	. . . .	. . .	. . . .	. . . .	. . . .
50	456	308,500	1237.0	2.89	3.53	0.64	4.00	1.11
100	506	318,000	1264.6	5.18	6.72	1.54	8.00	2.82
150	556	327,500	1290.5	7.33	9.90	2.57	12.00	4.67
200	606	336,000	1315.6	9.45	12.75	3.30	16.00	6.55
250	656	341,500	1340.5	11.50	14.60	3.10	20.00	8.50
300	706	347,000	1365.3	13.55	16.45	2.90	24.00	10.45

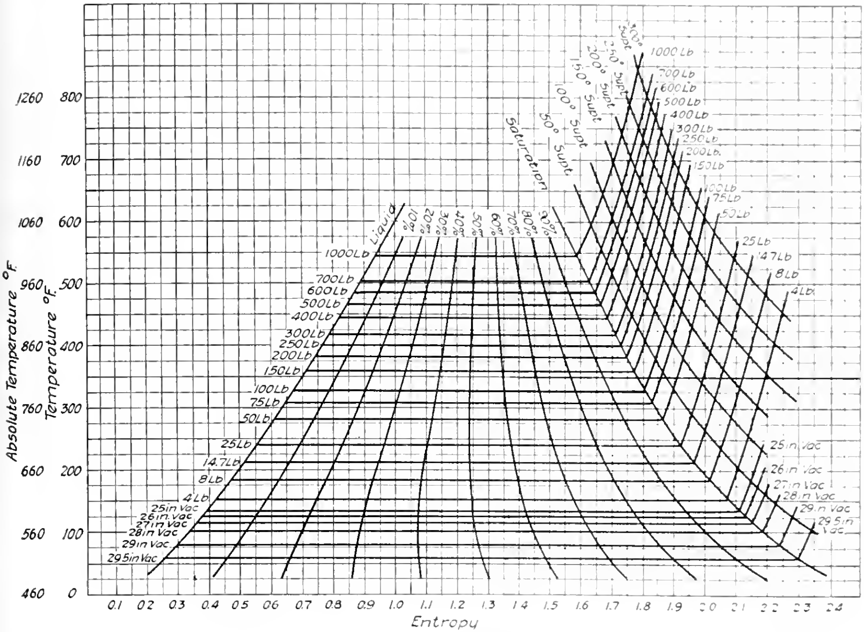


Fig. 1. Entropy-Temperature Curves

Effect of Moisture on Friction

A great many formulae and curves are given by various authors based upon experimental and theoretical data for calculating the friction losses, and they all have a constant which varies according to the conditions of the steam. Prof. Moyer, for example, in his book on steam turbines gives a formula for rotation losses of buckets and wheel disks in which the constant is as follows

100 deg. superheat	$C = 0.875$
50 deg. superheat. .	$C = 0.93$
0 deg. superheat. . .	$C = 1.00$
5 per cent moisture	$C = 1.08$
10 per cent moisture .	$C = 1.25$
20 per cent moisture .	$C = 2.00$

In other words, the friction loss is twice as great with 20 per cent moisture as it is with dry steam.

The gain by the use of superheat is often expressed by saying that the water rate is reduced one per cent for a certain number of

TABLE IV

TABLE COMPARING QUALITY OF STEAM IN VARIOUS STAGES, WHEN DRY INITIAL STEAM AND STEAM HAVING 250 OF SUPERHEAT IS USED

Stages	1	2	[illegible]	4	5	6	7	[illegible]	[illegible]	[illegible]
Quality of Steam					[illegible]					
Dry Initial.	4.4	6.8	8.15	9.8	11.5	13	14.5	16	17.5	18.7
Quality of Steam		Degrees Superheat					[illegible]			
250° Superheat.	160	120	75	30	.6	2	4	6.5	8	10.5

degrees superheat. This decrease varies with different turbines, a figure frequently used is one per cent gain for every 12.5 deg. superheat.

There is, of course, considerable saving in the size of auxiliaries by the use of superheat, but this is outside the scope of this article.

Effect of Throttling

Throttling of dry steam always produces superheat; and it has often been said for this reason that there is practically no loss due to throttling, which is true as far as heat

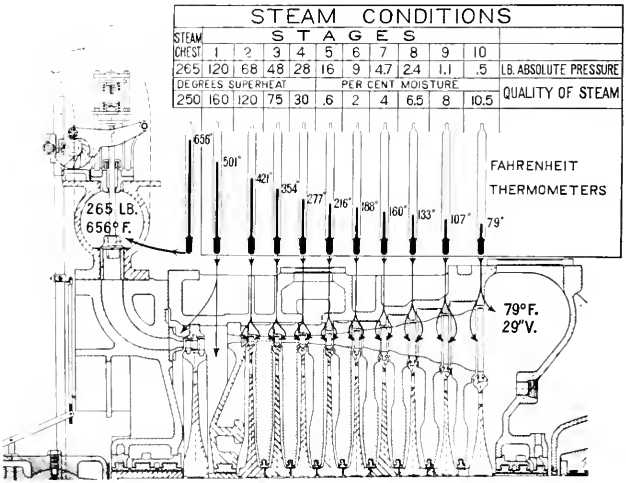


Fig. 2. Section of Ten-stage Turbine, showing Condition of Steam in Each Stage

is concerned. There is, however, a considerable loss of available energy. The amount of superheat obtained by throttling is easily calculated because the total heat before and after throttling is the same. Assume that steam at 200 lb. absolute pressure is throttled down to 100 lb. absolute pressure:

Total heat of dry steam at 200 lb. abs. = 11.981

Total heat of dry steam at 100 lb. abs. = 1186.3

Assume that the specific heat of steam is 0.5:

$$1198.1 = 1186.3 + 0.5 \times t_1 = 23.6 \text{ deg.}$$

The available energy, however, assuming that the steam in both cases is expanded to 28.5 in. vacuum, is:

With 200 lb. pressure, dry steam = 270,800 ft.-lb.

With 100 lb. pressure, 23.6 deg. superheat = 240,200 ft.-lb. or a loss in available energy of about 11 per cent.

Gain by the use of High Steam Pressure and Superheat

The gain by the use of high pressure and superheat is best shown by Fig. 3 which gives the ratio of available B.t.u. in steam to the total heat in the steam, returning the feed water at a temperature of 90 deg.

The present practice for power houses in this country is to use, with turbine drive, a steam pressure of 200 lb. gauge and about 150 deg. superheat with a vacuum of 28.5 in. From this curve in Fig. 3 it will be seen that the ratio of maximum available heat to the total heat is only about 31.25 per cent.

Steam temperatures as high as 700 deg. Fahr. are now used in Europe, which with a steam pressure of 500 lb. would give 233 deg. superheat. The ratio of heat available for work would then be about 36.3 per cent, a fuel saving over ordinary conditions of 16 per cent.

Turbine generator sets are now built having an overall efficiency of over 80 per cent including generator losses, which with a boiler efficiency of 80 per cent would give an efficiency from fuel amounting to:

$$36.3 \times 0.80 \times 0.80 = 23.25 \text{ per cent}$$

1 kw-hr. = 3412 B.t.u., therefore the B.t.u. required to produce one kw-hr. at the switchboard $= \frac{3412}{23.25} = 14{,}600$.

On the other hand had 800 lb. pressure and 800 deg. temperature been used, the efficiency would have been 38.75 per cent; and using a turbine efficiency of 85 per cent, and a boiler efficiency of 88 per cent (which is obtainable with liquid fuel, forced draft, and preheated combustion air), a kilowatt-hour could be obtained by:

$$38.75 \times 0.88 \times 0.85 = 29 \text{ per cent or}$$

$$\frac{3412}{0.29} = 11{,}750 \text{ B.t.u. or}$$

$$\frac{11{,}750}{19{,}000} \text{lb. of fuel oil} = 0.62 \text{ lb.}$$

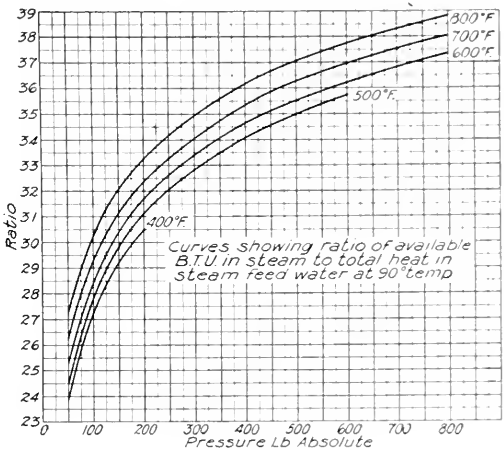


Fig. 3

Advocates of Diesel engines claim about 0.55 lb. per kw-hr., but the fuel costs about 50 per cent more.

It will, therefore, be seen from these figures that those who predict a great future for Diesel engines have not considered improvements that can be made and are bound to be made in steam plants.

Voltage Regulation of Three-phase Feeders by Automatically Controlled Induction Regulators

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This article treats of the voltage regulation of a three-phase feeder by one three-phase automatic induction regulator and by two or three single-phase automatic induction regulators. These three means are each thoroughly discussed and the conclusion is drawn that two single-phase regulators will maintain a better regulation on a three-phase three-wire feeder, carrying mixed power and lighting load, than will a three-phase regulator (the cost, losses, and efficiency of either method of regulation will be practically the same). In case it is desired to obtain the best possible regulation on all the three phases, a third single-phase regulator should be added.—Editor.

Introduction

The importance of maintaining constant voltage at the consumers' terminals at all values of load is so well recognized by operating companies as to need no further discussion. Methods of compensating for line drop in single-phase, two-phase, and three-phase feeders were discussed in the General Electric Review, December 1912, page 793. The following article will deal exclusively with three-phase, three-wire feeders, and an attempt will be made to compare the results which are obtainable with the various means of regulation described in the earlier article.

The following means of controlling the voltage of three-phase feeders are in successful use in a great number of installations:

One three-phase automatic induction regulator.
Two single-phase automatic induction regulators.
Three single-phase automatic induction regulators.

Connection diagrams of the three combinations are shown in Figs. 1, 2, and 3.

If the load is *balanced*, any one of these means of regulation will give correct results. If the load is *unbalanced*, the regulation of all three phases will be correct only in case three single-phase automatic induction regulators are used. Because of the difference in cost, etc., of the three means of regulation, it is important to know what the discrepancy in voltage of the unregulated phase or phases may be for a certain feeder, and a study of the variations will be made in the following.

It will be shown that the results when using the different means of regulation will depend upon the following factors:

Line resistance and line reactance.
Unbalancing of current.
Power-factor of load.
Phase rotation.
What phase or phases are regulated.

Because of the large number of factors influencing the regulation, it is evident that the solution of the problem will be somewhat complex; therefore the general method of determining the voltage of the unregulated phase or phases will be shown, and results will be worked up for a feeder where some of the factors are known.

General Solution

Vector Diagram

The vector diagram of a single-phase line is shown in Fig. 4.

A similar vector diagram for a three-phase feeder is given in Fig. 5 which shows the conditions for unbalanced load. The line drop is the difference between the balanced generator voltage ABC and the load voltage $A_1B_1C_1$. In order to maintain one or more of the phase voltages constant

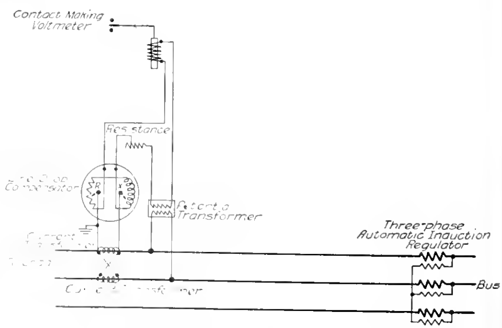


Fig. 1 One Automatic Three-phase Induction Regulator Connected on a Three-phase System

at the load, the line voltage (or voltage at the start of the feeder) has to be increased. The vector diagrams of the three means of regulation are shown in Figs. 6, 7, and 8.

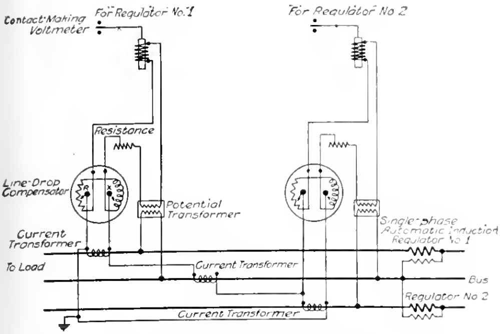


Fig. 2. Two Automatic Single-phase Induction Regulators Connected on a Three-phase System

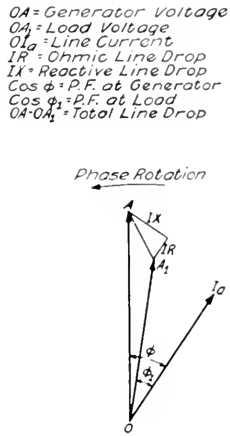


Fig. 4. Vector Diagram for Single-phase Feeder

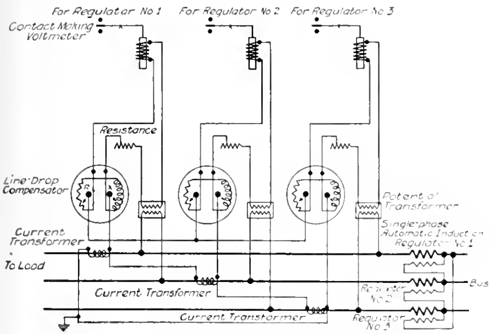
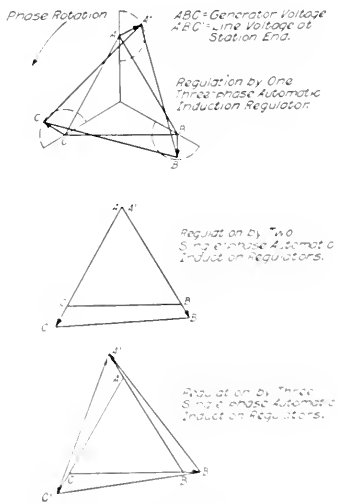


Fig. 3. Three Automatic Single-phase Induction Regulators Connected on a Three-phase System



Figs. 6, 7, and 8. Voltage Diagrams of Three-phase Feeders Controlled by Automatic Voltage Regulators

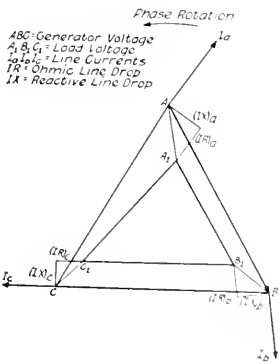


Fig. 5. Vector Diagram for Three-phase Feeder

In using a three-phase automatic induction regulator, the voltage of all three phases is varied an equal amount, the amount depending upon what the regulated phase demands.

In using two single-phase automatic induction regulators, the voltages of two phases are regulated independently of each other in accordance with the demand. The complete vector diagram of a feeder thus regulated is shown in Fig. 9. In this diagram the generator voltage is represented by ABC, and $A_1B_1C_1$ would represent the load voltage if no regulators were used. However, by the use of two single-phase automatic induction regulators, connected to the feeder at B and at C, the voltages of phases AB and AC may be controlled; and the diagram shows that voltage BB'' is added to generator voltage AB, and CC'' to generator voltage AC, so that the voltage at the station end of the feeder becomes $AB''C''$. As the line drop remains unchanged, it is apparent that the load voltage now becomes $A'B'C'$. The voltages $A'B'$ and $A'C'$ are determined by the adjustment of the line-drop compensators, and if these are properly made the voltages will be constant for all values of load. It is apparent that the load voltage $B'C'$ is not under control.

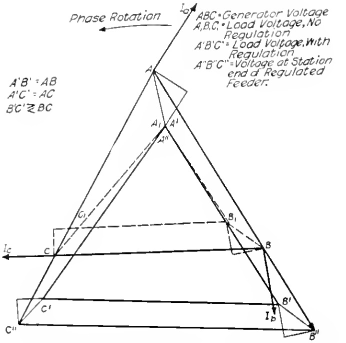


Fig. 9. Voltage Diagram of Three-phase Feeder Controlled by Two Automatic Single-phase Induction Regulators

In using three single-phase automatic induction regulators the voltages of all three phases are varied in accordance with the demand, but not independently of each other, as the movement of any one regulator to vary the voltage of its phase affects the voltage to some extent of one adjacent phase, and if it causes the regulator of this phase to move, it affects also the voltage of the third phase. Obviously, for any considerable change in load all regulators may move; however "hunting" as generally understood does not occur in practice.

Line Resistance and Line Reactance

The actual values of line resistance and reactance must be known. They can be calculated either from the dimensions of the line or from tests.

It should be noted that the values of ohmic and reactive line drop for one conductor or line are $\frac{1}{\sqrt{3}}=58$ per cent of the values between lines.

Unbalancing of Current

The actual values of the currents in the three lines should be known in order to solve the problem correctly.

The amount of unbalancing in current is often given in per cent. This is meaningless unless properly defined; and as no authoritative definition seems to have been given, the following will be used:

$$\text{Per cent unbalancing} = \frac{\text{Maximum deviation from average}}{\text{Average}}$$

Example: $I_a = 85$ amp. $I_b = 103$ amp. $I_c = 112$ amp.
Average $\frac{1}{3}(85+103+112) = 100$ amp.
Max. deviation $= 100 - 85 = 15$ amp.
Unbalancing $= 15/100 = 15$ per cent.

It should be noted, however, that the relative values of current in the three lines are not defined by the knowledge of the per cent unbalancing in current. This can readily be seen by referring to the preceding example and to Fig. 10. It is evident that

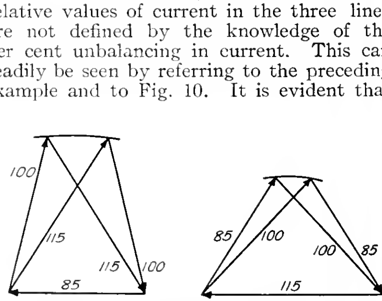


Fig. 10. Current Diagram for Three-phase Feeder

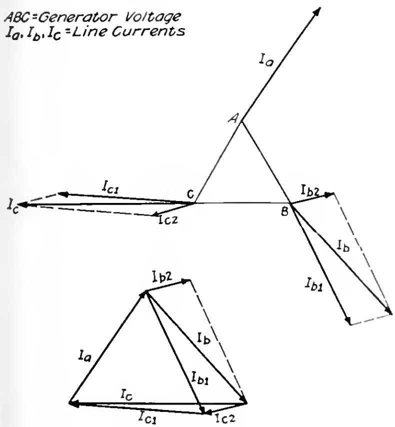
if the unbalancing is 15 per cent one of the currents is either 85 or 115 per cent of normal. In the former case, the other two currents may have any value between 100 and 115 per cent of normal; while in the latter case, they may have any value between 85 and

100 per cent of normal, the average of these currents being in all cases 100 per cent of normal.

Besides the per cent unbalancing in current, it would also be necessary to have knowledge of the load so that the current in the three lines may be calculated or estimated.

The general solution of the problem is made somewhat easier by taking advantage of the fact that unbalanced three-phase currents can always be resolved into two components: one balanced three-phase and one single-phase current.

The proof of this statement can readily be obtained by referring to Figs. 11 and 12. As the vector sum of the unbalanced currents I_a I_b I_c is zero, the vectors must form a closed triangle if added geometrically, as in Fig. 12. In resolving the unbalanced currents into their two components, the balanced three-phase and the unbalanced single-phase, any one of the three line currents may be chosen as the basis. In the diagrams, I_a has been chosen as the basis, and I_b is divided into two components one of which is I_{b1} equal to and displaced 120 degrees from I_a. Similarly, I_c is divided so that I_a, I_{b1}, and I_{c1} form a



Figs. 11 and 12. Current Diagram of Three-phase Feeder.

60-degree triangle and represent the balanced three-phase current. It will readily be seen that components I_{b2} and I_{c2} are of equal value, and are 180 degrees displaced; these represent the single-phase current. It is generally preferable to choose the smallest current vector as the base for it will give a lagging single-phase component.

It may be of general interest to state that no matter which one of the line currents in the triangle is used as a base for the balanced

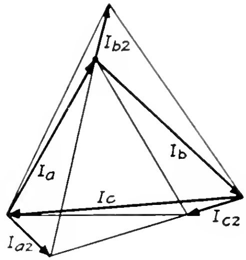


Fig. 13. Current Diagram of Three-phase Feeder

component, the unbalanced components will in all three cases be of equal value, and will be displaced 120 degrees as shown in Fig. 13. It should also be noted that the unbalanced single-phase currents thus obtained may be either leading or lagging, even if the unbalancing is due to 100 per cent power-factor load.

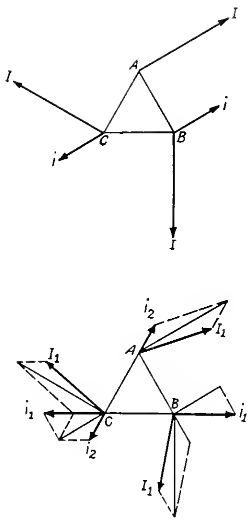
Although of no direct bearing upon the problem under consideration, it may be of further interest to note that the combination of a balanced three-phase current and a single-phase current of any power-factor can be resolved into a balanced three-phase current and single-phase currents on two phases, the single-phase currents being in phase with the voltages. The correctness of this statement can easily be proved by referring to Figs. 14 and 15. Fig. 14 shows a balanced three-phase current I and single-phase current i across phase BC. Fig. 15 shows vectorially how the combined currents may be divided up into the balanced three-phase current I_1, and the single-phase current i_1 across phase BC, and the single-phase current i_2 across phase AC, the power-factor of the single-phase currents being 100 per cent.

Power-factor of Load

It is necessary that the power-factor be at least approximately known.

Inasmuch as indicating power-factor meters are designed for use only on approximately balanced circuits, it is preferable under unbalanced conditions to estimate the power-factor of the balanced and the unbalanced current components of the load.

The power-factor at the load will generally be somewhat better than at the generator, on account of the reactance of the lines. It will simplify the problem to consider the



Figs. 14 and 15. Current Diagram of Three-phase Feeder

power-factor at the generator, and this can be calculated approximately from the data of the line and the load.

Phase Rotation

A study of the vector diagram will show that a reversal of phase rotation will generally have quite an effect upon the voltage of the unregulated phase or phases. In order to pre-determine what the voltage will be across the unregulated phase or phases of a certain feeder, it is therefore necessary to know the phase rotation.

What Phase or Phases are Regulated

When considering the regulation of one or two phases, it is not always apparent which phase or phases should be regulated in order to get the best results on the unregulated phase or phases. That the results may vary considerably will be shown in the following example.

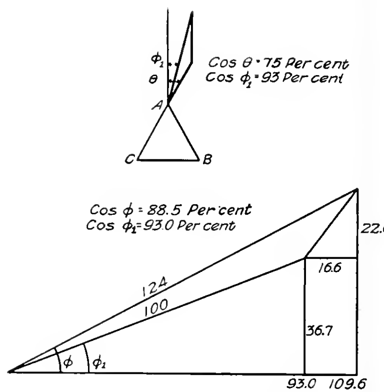
Example

What will be the voltage at the center of distribution of a three-phase feeder when it is unregulated and when it is automatically regulated by a three-phase induction regulator, by two single-phase induction regulators, or by three single-phase induction regulators; the feeder having the following characteristics:

Length,	3 miles
Conductor No. 00 B.&S.	0.365 in. dia.
Conductor spacing	12 in. triangle
Voltage (normal)	2300 volts
Frequency	60 cycles
Current (normal)	150 amperes
Unbalancing	15 per cent
Line current due to motors is about	50 per cent
Line current due to lamps is about	50 per cent
Power-factor of the motors is about	75 per cent
Power-factor of the lamps is about	100 per cent

From the given information, the following data are calculated:

Resistance per conductor (3 miles)	1.21 ohms
Reactance per conductor (3 miles)	1.61 ohms
Resistance drop per conductor at 150 amp.	181 volts
Resistance drop between lines at 150 amp. 313 volts	= 13.6 per cent
Reactance drop per conductor at 150 amp.	242 volts
Reactance drop between lines at 150 amp. 417 volts	= 18.1 per cent



Figs. 16 and 17. Vector Diagram of Three-phase Feeder.

As the current values in the three lines are not given, the extreme case for 15 per cent unbalancing will be assumed; i.e.,

I_a = 85 per cent = 127.5 amp.
I_b = 100 per cent = 150.0 amp.
I_c = 115 per cent = 172.5 amp.

The currents are made up of approximately 75 amperes balanced motor currents at 75 per cent power-factor, and the remainder is unbalanced lamp current at 100 per cent power-factor.

By means of the graphic method shown in Fig. 12 (which is drawn to scale) the unbalanced current is resolved into a balanced three-phase component of 127.5 amperes and an unbalanced single-phase component of 46 amperes.

If the load were balanced and equal currents were taken by the motors at 75 per cent power-factor and by the lamps at 100 per cent power-factor, the combined power-factor of the load would be 93 per cent as shown graphically in Fig. 16.

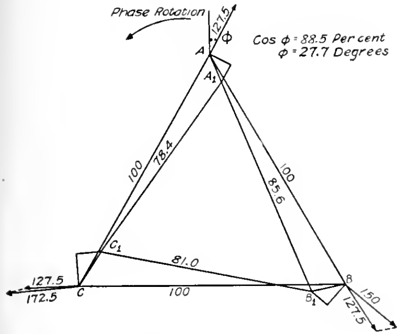


Fig. 18. Vector Diagram of Three-phase Feeder, Counter-clockwise Phase Rotation

The power-factor at the generator bus may be roughly estimated as follows.

The reactance component of the balanced load at 93 per cent power-factor is 36.7 per cent, and the resistance component is 93 per cent of the load voltage. The reactance drop of the line has previously been calculated to be 18.1 per cent and the ohmic drop 13.6 per cent of the generator voltage. A rough approximation shows that the generator voltage will be about 18 per cent higher than the load voltage, so that if the line drop is referred to the load voltage the values just given will be 22.0 and 16.6 per cent respectively. Graphically, the power-factor at the generator is found to be 88.5 per cent as shown in Fig. 17. This value would be correct in case the load were balanced. With any kind of load the average power-factor is the ratio of the kilowatt- and the kilovolt-amperes of the load; and while it is possible to determine the exact power-factor in the case being considered it would complicate the discussion. If it is assumed that the average power-factor of the balanced load component of the unbalanced load is 93 per cent a small error is introduced, but this is more than offset by the error that may be introduced from the lack of exact knowledge and subsequent assumption of current values for the three lines. In the following, therefore, the power-factor of the balanced component of the load will always be assumed to be 93 per cent.

From the data now available, the relationship of generator voltage and line current may be drawn graphically as in Fig. 18 for counter-clockwise and as in Fig. 19 for clockwise phase rotation. These diagrams also show the voltage drop in the various lines, thus giving the voltages at the end of the line, or at the load.

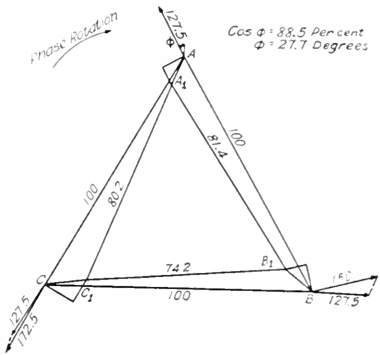


Fig. 19. Vector Diagram Three-phase Feeder, Clockwise-phase Rotation

TABLE I

VOLTAGE AT END OF FEEDER IN PER CENT OF NORMAL VOLTAGE

No Voltage Regulation

Phase Voltage	Phase Rotation C.C.W.	Phase Rotation C.W.
A_1 B_1	85.6	81.4
B_1 C_1	81.0	74.2
C_1 A_1	78.4	80.2
Average	81.7	78.6

The results in Table I show that in a three-phase feeder with unbalanced load the voltage

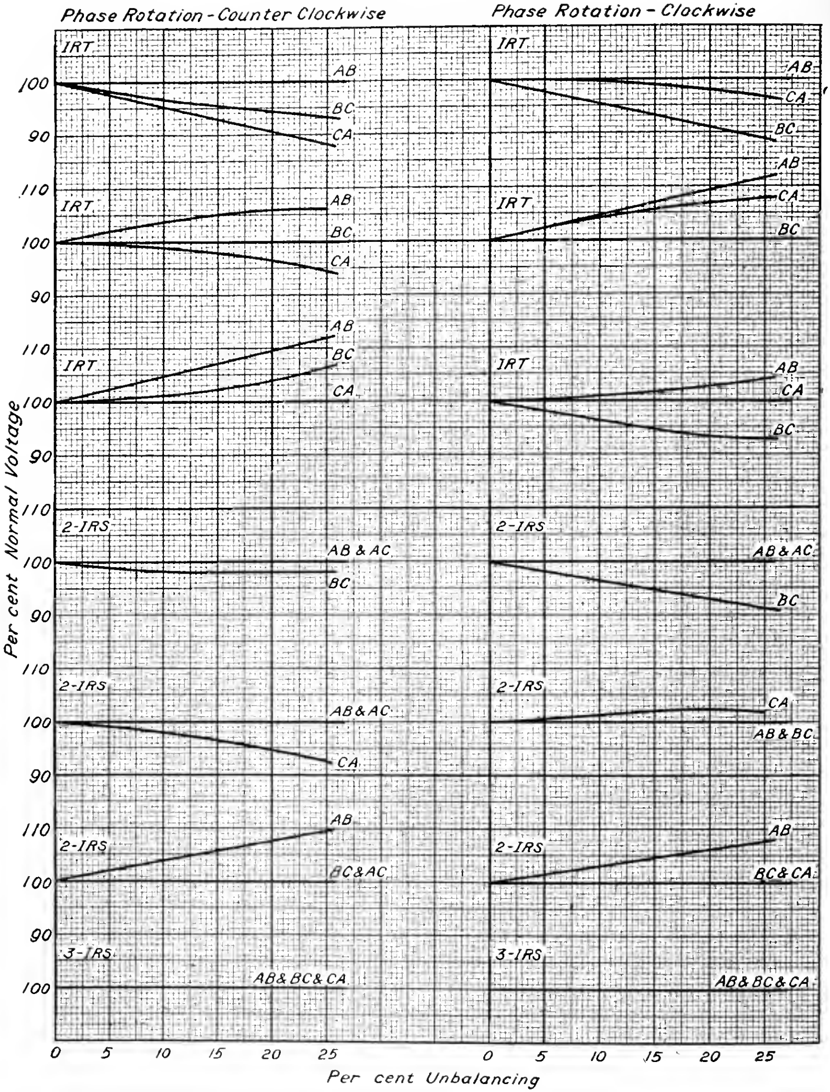


Fig. 20. Voltage regulation of a Three-phase Feeder by one Three-phase Automatic Induction Regulator (IRT) and by Two and Three Single-phase Automatic Induction Regulators (IRS)

at the end of the line will depend upon the phase rotation; i.e., in order to determine the voltage at the end of a line carrying certain currents it is necessary that the phase rotation be known.

It should be noted, however, that if the phase rotation is reversed in a feeder which carries a definite unbalanced load the current values in the lines will also change; so that while the drop across the various phases may change, due to the phase reversal, the average drop will remain the same.

It is apparent from the foregoing how to determine the voltages at the end of the line when regulators are used, and in the following only the results will be given. It may be stated that no account is taken of the resistance and reactance drop in the regulators as the values are small and will not materially affect the results.

TABLE II

VOLTAGE AT END OF FEEDER IN PER CENT OF NORMAL VOLTAGE

Regulation by a Three-phase Automatic Induction Regulator

Regulated from Phase	Phase Voltage	Phase Rotation C.C.W.	Phase Rotation C.W.
A_1 B_1	A_1 B_1	100.0	100.0
	B_1 C_1	95.4	92.8
	C_1 A_1	92.8	98.8
B_1 C_1	A_1 B_1	104.6	107.2
	B_1 C_1	100.0	100.0
	C_1 A_1	97.4	106.0
C_1 A_1	A_1 B_1	107.2	101.2
	B_1 C_1	102.6	94.0
	C_1 A_1	100.0	100.0

From Table II it will be seen that, with the various combinations, the voltage of the unregulated phases may vary from 1.2 to 7.2 per cent from normal. The best regulation is obtained by regulating from phase $C_1 A_1$ with clockwise phase rotation, in which case the voltage of the unregulated phases is 1.2 per cent above and 6.0 per cent below normal.

From Table III is will be seen that, with the various combinations, the voltage of the unregulated phase may vary from 1.8 to 6.7 per cent from normal or from 6.7 per cent below to 5.5 per cent above normal.

The best combination is obtained by regulating from phases A_1B_1 and A_1C_1 with counter-clockwise phase rotation, in which case the voltage of the unregulated phase is 2.2 per cent below normal.

TABLE III

VOLTAGE AT END OF FEEDER IN PER CENT OF NORMAL VOLTAGE

Regulation by Two Single-phase Automatic Induction Regulators

Regulated from Phase	Phase Voltage	Phase Rotation C.C.W.	Phase Rotation C.W.
A_1 B_1	A_1 B_1	100.0	100.0
&	B_1 C_1	97.8	93.3
A_1 C_1	C_1 A_1	100.0	100.0
B_1 A_1	A_1 B_1	100.0	100.0
&	B_1 C_1	100.0	100.0
B_1 C_1	C_1 A_1	95.5	101.8
C_1 A_1	A_1 B_1	105.5%	104.0%
&	B_1 C_1	100.0	100.0
C_1 B_1	C_1 A_1	100.0	100.0

TABLE IV

VOLTAGE AT END OF FEEDER IN PER CENT OF NORMAL VOLTAGE

Regulation by Three Single-phase Automatic Induction Regulators

Regulated from Phase	Phase Voltage	Phase Rotation C.C.W.	Phase Rotation C.W.
A_1 B_1 &	A_1 B_1	100.0	100.0
B_1 C_1 &	B_1 C_1	100.0	100.0
C_1 A_1	C_1 A_1	100.0	100.0

Table IV shows that the use of three single-phase automatic induction regulators give correct results under all conditions.

The specific problem is herewith solved and it shows:

First—One three-phase automatic induction regulator gives perfect regulation of one phase; and, under most favorable conditions, one of the unregulated phases will be 1.2 per cent above and the other 6.0 per cent below normal.

Second—Two single-phase automatic induction regulators give perfect regulation of two phases; and, under most favorable conditions, the unregulated phase will differ only 2.2 per cent from normal.

Third—The use of three single phase regulators gives perfect regulation on all phases regardless of the unbalancing or phase rotation.

Fourth—In regulating only one or two phases, the phase rotation and the selection of regulated phases will greatly affect the voltage of the unregulated phases or phase. The best combination can be determined from theoretical considerations.

If it is desired to maintain the voltage at the center of distribution on all phases within 4 per cent below or above normal, it is evident that two single-phase automatic induction regulators, taking into account first cost, will give the best results.

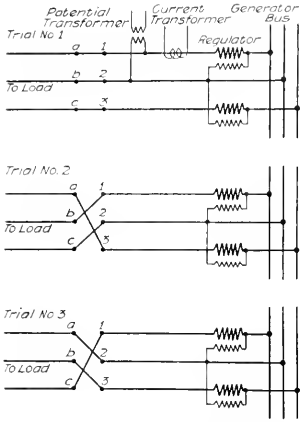


Fig. 21. Connections of Two Single-phase Automatic Induction Regulators on a Three-phase Three-wire System

General Discussion

It is of interest to make a further study of this problem, assuming different percentages of unbalancing in current. It will be assumed that the motor load as well as the lamp load varies in such a way that the motor current equals the balanced part of the lamp current; i.e., the power-factor of the balanced current component remains constant at 88.5 per cent. The results of this investigation are given in Fig. 20 which shows the voltage at the center of distribution when using the three means of regulation with the counter-clockwise or the clockwise phase rotation.

These curves clearly show the importance of selecting the proper phase or phases for regulation in order to obtain the best results on the unregulated phase or phases. While the selection can be predetermined from theoretical considerations, the required data are generally not readily obtained and it seems preferable to make the selection from trial since only three combinations are possible, for the phase rotation in each case is fixed.

Fig. 21 shows that such a trial can be made with comparative ease by merely changing the connections between the regulator and the outgoing line. This change will not reverse the phase rotation so that the load will not be disturbed in any way.

The curves in Fig. 20 also show the excellent results obtainable by means of two single-phase automatic induction regulators. In selecting the proper phases for regulation, the error in the voltage of the unregulated phase is only slightly over 2 per cent even when the current unbalancing is as high as 25 per cent. It should, of course, be borne in mind that the curves refer to a definite case, while any number of variations will occur in practice. Particular consideration should be given to the fact that the load distribution on a feeder may vary from time to time so that the best location of the regulator at one time may not be best at all times, and in such a case the best average should be selected.

It would seem from these curves, and it has also been confirmed in practice, that the regulation of a three-phase three-wire feeder carrying mixed power and lamp load is most economically obtained by means of two single-phase automatic induction regulators. The cost, losses, and efficiency of two such regulators are generally not materially different from that of a three-phase automatic induction regulator, and besides giving better regulation they allow of more flexibility: e.g., the single-phase regulator may be used for regulating a single-phase, two-phase, or three-phase feeder, and in case it is desired to obtain perfect regulation of all three phases of a three-phase feeder, a third single-phase regulator can be added.

Size of Regulators

It may be of interest to discuss the rating of the regulators for use on three-phase feeders.

TABLE V

Regulation	Regulator Voltage in Per Cent of Bus Voltage		
	AA′	BB′	CC′
One three-phase regulator....	5.8	5.8	5.8
Two single-phase regulators.........	0	10.0	10 0
Three single-phase regulators...	6.7	6.7	6.7

In the example considered it is necessary to increase the feeder voltage about 20 per cent in order to compensate for the line drop. It is not good practice to obtain this increase in voltage by regulators only as they would be needlessly large due to the fact that only their boosting range would be utilized, no advantage being taken of the lowering range. It would, therefore, be preferable to boost the bus voltage permanently 10 per cent, either by increasing the generator voltage or by providing an auto-transformer, and then to obtain the 20 per cent range in voltage by regulators which will boost the line 10 per cent and lower the line 10 per cent.

In the case considered, the bus voltage should be increased to 2530 volts and the regulators should be able to add or deduct 230 volts, so that at the station end of the feeder the voltage is variable between the limits of 2300 and 2760 volts.

Referring to Figs. 6, 7, and 8 it will be seen that in order to obtain a 10 per cent increase or decrease of the bus voltage ABC ($AB = BC = CB = 100$ per cent; and $A'B' = B'C' = C'B' = 90$ or 110 per cent) the values of regulator voltage required are as given in Table V.

The kilovolt-ampere capacity of a regulator is equal to the product of the line current, the voltage boost or lower (of each phase winding), and the number of phases, divided by 1000. Therefore, for the case considered, Table VI furnishes the data.

This table shows that in order to obtain equal range in feeder voltage it is necessary to provide slightly larger combined kilovolt-ampere capacities of single-phase automatic induction regulators. This is, however, of only minor importance when considering that regulators of the nearest standard rating should be selected.

TABLE VI

Regulation	Voltage per Phase Winding	Line Current	Regulator Kv-a	
			Total	Per Cent of Feeder
One three-phase regulator	147	150	66.2	10.0
Two single-phase regulators	253	150	2 x 38.0 = 76.0	11.5
Three single-phase regulators	170	150	3 x 25.3 = 76.0	11.5

Effect of Artificial Light on the Growth and Ripening of Plants

By J. L. R. Hayden and C. P. Steinmetz

Consulting Engineering Department, General Electric Company

Of the myriad uses of electric light perhaps the most unique is its application to stimulate plant growth and fruition. A hitherto unpublished investigation of this application appears in the following columns. A description is given of the procedure, which was conducted in a scientific manner, and the results are instructively presented in the form of progressive photographs, tabulations, and curves. Based upon these facts, the conclusions of the investigation show that under certain conditions electric light may be used with commercial success to accelerate the growth and development of plants.—Editor.

The investigation described in this article was made to determine how much the growth and the ripening of plants could be speeded up by intense artificial illumination.

Equipment

Gas-filled Mazda lamps were used as the source of light since previous experiments in Dr. Steinmetz's laboratory had shown that the quality of light from this lamp is very efficient in its action on plant growth.

As a check test the same kind of beans were planted in a box about 36 inches square, filled with the same soil and located on the other side of the room outside the rays of the Mazda lamps.

Procedure

The planting was done and the experiment started on December 13, 1916, and the experiment was discontinued 73 days later on February 24, 1917.

Figs. 1 and 2. Check Plants Two and Four Weeks after Planting

The investigation was made on beans as the natural life of the bean plant is relatively short, and it was therefore possible to get results in a fairly short time.

A piece of ground 5 feet by 9 feet having good black soil was selected in Dr. Steinmetz's orchid house.

Five 500-watt gas-filled Mazda lamps were hung in a row 36 inches above the ground and 17 inches apart from each other. These lamps had floodlighting reflectors which directed the light on the bed. The power consumption was 2.5 kw.

Henderson's dwarf wax-bush beans were used, and three rows were planted 18 inches apart.

The Mazda lamps were kept burning continuously, 24 hours per day, in addition to the daylight, while the beans in the check test had only the daylight. After 44 days three of the lamps were turned off and only two left burning during the last 29 days, representing a power consumption of 1 kw.

Twenty of the 73 days were cloudy, about evenly distributed, representing about the average condition of climate in Schenectady during the winter months.

The temperature of the greenhouse averaged 18 to 20 deg. C, but above the experimental bed, in the rays of the lamps, the temperature averaged about 2 deg. C. higher.

Records of the average height and the state and other conditions of the plants were taken almost daily, and photographs were taken every two weeks.

Figs. 1 and 3 are photographs of the experimental bed and the check plants two weeks after planting; Figs. 2 and 4, four weeks after planting.

Fig. 3. Experimental Bed Two Weeks after Planting

Fig. 4. Experimental Bed Four Weeks after Planting

Table I gives an abstract of the records taken during the progress of the experiment. Since individual plants, raised under the same conditions, vary materially in their growth two groups of observations were taken and recorded. The A data are of the average condition of the most advanced plants, about one quarter of the total number; and the B data the average condition of all the plants.

Fig. 5 shows the growth curves of the bean plants. Curves A_1 and B_1 are of those grown under intense artificial illumination; and curves A_2 and B_2 of those grown under daylight only as a check test. Curves A_1 and A_2 are the average of the maximum advanced plants, B_1 and B_2 the average of all the plants.

It is interesting to note the difference in the shape of the curves: the rapid growth of B_1 coming to a standstill six weeks after planting, when ripening begins, and the slow growth of B_2 which is not yet completed after nine weeks.

Between 25 and 65 days B_2 grows an average of 0.16 in. per day; between 15 and 35 days B_1 grows an average of 0.43 in. per day, or 2.6 times as rapidly.

Table II gives the number of days after planting when the different stages of development were reached in the four cases, by the more advanced plants and by the average, under continuous intense artificial illumination in addition to daylight, and under daylight alone.

Table III gives the gain, in days and in per cent, in the development of the plants brought about by intense artificial illumination. This gain is fairly uniform in the development of the foliage, in the appearance and development of the flowers and fruits, and averages 46 per cent. That is, the artificial illumination has reduced the time required for the development by 46 per cent.

This means that under the influence of intense artificial illumination the plants have grown and brought fruit in a little more than half the time required under daylight alone; in other words, the artificial light causes about double the rapidity of growth and development, or it saves about as much time as the time during which the intense illumination is maintained.

Discussion of Results

2.5 kw., used in five lamps for illuminating 5 by 9 = 45 sq. ft. of ground, gives a power consumption of 55 watts per square foot.

With a lamp efficiency of 0.6 watts per spherical candle power, the total light flux of the five lamps is $\frac{4\pi \times 2500}{0.6} = 52{,}000$ lumens. Of this probably about 60 per cent, or 31,000 lumens, reaches the ground, the remainder being stray light or absorbed in the reflectors. This gives an intensity of illumination of about 700 lumens per square foot.

The intensities of illumination are very much higher than any ever considered for illumination and approach the magnitude of sunlight illumination. This is necessary to get results comparable with those of sunlight.

Three quarts of string beans were gathered. At winter prices this represents about 90

TABLE I

		UNDER LIGHT			
No. of Days Since Planting	No. of Lamps Burning	A₁. Average of Most Advanced Plants		B₁. Average of All Plants	
		Height in In.	Remarks	Height in In.	Remarks
0	5	..	..	..	..
6	5	0	Up	..	..
7	5	2½	Germ leaves unfolding	0	Up
8	5	3½	Germ leaves unfolded	..	..
10	5	5½	Center leaves unfolding	..	..
13	5	9	..	..	Germ leaves unfolded
14	5	..	Photograph, Fig. 3	..	..
16	5	..	22° C. (19.5° C. room)	..	..
17	5	..		8	Center leaves unfolding
21	5	10½	Buds	..	Center leaves unfolded
27	5	16	Photograph, Fig. 4	11	Buds
30	5	17½		13	..
35	5	..	20° C. (18.5° C. room)	..	..
36	5	..	Beans	16	..
42	5	..	..		..
44	5	..	5-in. bean	16	Beans
55	2	..	1 qt. string beans	..	..
61	2	..	1 qt. string beans	16	..
66	2	..	..	..	Plants dying
73	2	..	1 qt. string beans		Discontinued
..	..	..	Discontinued	..	..

		CHECK TEST			
No. of Days Since Planting	No. of Lamps Burning	A₂. Average of Most Advanced Plants		B₂. Average of All Plants	
		Height in In.	Remarks	Height in In.	Remarks
0	5	..	..	..	..
6	5	..	..	..	..
7	5	0	Up	..	..
8	5	..	..	..	..
10	5	½	..	..	..
13	5	3½	Germ leaves unfolding	2½ and less	..
14	5	..	..	..	..
16	5	..	18° C.	..	..
17	5	8	..	6 and less	..
21	5	10½	Stems thicker and germ-leaves much smaller than under light		
27	5	12	Center leaves unfolding	7	Germ leaves unfolded
30	5	..	Three center leaves	8	Center leaves unfolding
35	5	..	17° C.		..
36	5	14	Buds	8	3 small center leaves
42	5	..	..		..
44	5	15		9	..
55	2	..			..
61	2	..			..
66	2	..	Small beans	12	..
73	2	..	No bean large enough yet for use	13	..

cents. The power consumed by the lamps was 2.5 kw. during 24 hours for 44 days, and 1.0 kw. for 29 days, or a total of 3340 kw-hr. At a power rate of 5 cents per kw-hr., this would cost $167. Assuming that the power is kept on only 18 hours per day during off peak, and a rate of 2 cents per kw-hr. is secured, it would still represent a cost of $42 which is altogether out of proportion to the market value of the string beans. Thus it apparently would not pay to raise such relatively cheap products as string beans by artificial illumination.

Such speeding up of the growth and the flowering of plants by intense artificial illumination may, however, be entirely economical and advantageous when the product has a high market value at some definite time, but largely loses its value after that time—for instance Easter lilies, poinsettias, etc. These flowers are required at Christmas or Easter, and are in but little demand afterwards. If then, by a period of cloudy weather, their flowering threatens to be retarded beyond the time when the flowers are in demand their value may be saved by

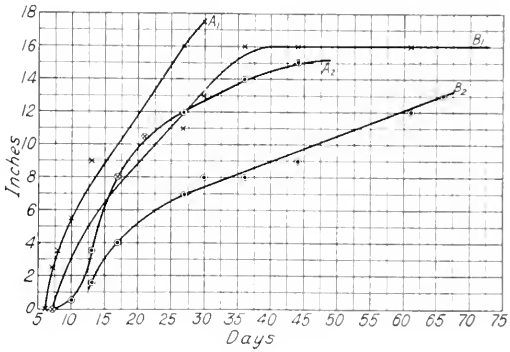


Fig. 5. Curve of Plants' Growth

TABLE II

NUMBER OF DAYS AFTER PLANTING

	UNDER LIGHT		CHECK TEST	
	Average of Most Advanced Plants A1	Average of All Plants B1	Average of Most Advanced Plants A2	Average of All Plants B2
Coming up	6	..	7	..
Germ leaves unfolding	7	.	13	
Germ leaves unfolded	8	13	.	27
Center leaves unfolding	10	17	21	36
Center leaves unfolded	.	21	30	
Buds	21	27	36	
Beans appearing	36	44	66	
First crop gathered	.	55	..	
Second crop gathered	.	61	.	
Last crop gathered	.	73		

TABLE III

	GAIN IN DAYS AND IN PER CENT	
	Days	Per Cent
Leaf formation:		
Germ leaves unfolding	6	46
Germ leaves unfolded	14	52
Center leaves unfolding	11-19	51-52
Center leaves unfolded	.	
Average	.	50
Buds	15	42
Beans	30	45.5
Total average	.	46

speeding up their development by intense artificial illumination for some days, and a considerable expense for power would then be economical.

Assume, for instance, that the plants are in 6-in. pots. By proper arrangement one 500-watt lamp could illuminate a circle 6 ft. in diameter, thus accommodating 144 pots. Intense illumination for one week or seven days, 18 hours per day, would accelerate the development by about five days and would require 63 kw-hr. At 5 cents per kw-hr., this would cost $3.15 or a little over 2 cents per pot, an expense which would be fully warranted economically if it makes the product salable at the high seasonal prices. Probably a materially higher cost for correcting a retardation of several weeks would be economical.

To a much larger extent intense artificial illumination to accelerate plant growth and development in greenhouses may become economical if the electric current is generated at extremely low cost by the heating plant. Assume that a high-pressure steam boiler is used in the heating plant as is frequently the case. Instead of the usual pressure-reducing valves a simple and cheap non-condensing steam turbine with electric generator is inserted between the high-pressure boiler and the radiators. In this case, the only cost of the light is the interest on the investment of the steam-turbine generator, depreciation, and attendance—the fuel costs nothing. The efficiency is, therefore, entirely immaterial; and a very simple, cheap, and fool-proof plant can be chosen, reducing the cost to a minimum. It must be realized that all the heat energy which is wasted by the inefficiency of the plant remains in the steam and is used in the steam heating, and that only as much heat energy is abstracted from the high-pressure steam as is represented in the electric power generated. This power, however, is converted into light, and the light, absorbed by the ground and the plants, is converted into heat, and so the heat energy abstracted from the steam by the electric plant finally also reaches the greenhouse as heat. Under such conditions the use of intense artificial illumination to accelerate plant life would be economical also with plants of relatively low value.

Conclusion

By intense artificial illumination, of the magnitude of 700 lumens per square foot, the rapidity of the growth and development of plants can be approximately doubled. Economically such use of light for raising plants may be justified where the electric current is generated as a by-product of the heating plant, but at any cost of purchased power it would be economically justified only for temporary use with plants which have a market value only at a definite time.

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"THE SHORT-HAUL RIDER TOOK THE FIRST VEHICLE PASSING . . . THE LONG-HAUL RIDER WOULD TAKE A JITNEY IN PREFERENCE TO THE STREET CAR . . . THESE CONDITIONS LED WESTERN ROADS TO ADOPT THE SAFETY CAR, A CAR OF HIGH SPEED WHICH IS VERY ESSENTIAL IN MEETING JITNEY COMPETITION." (See page 281.

General Electric Review

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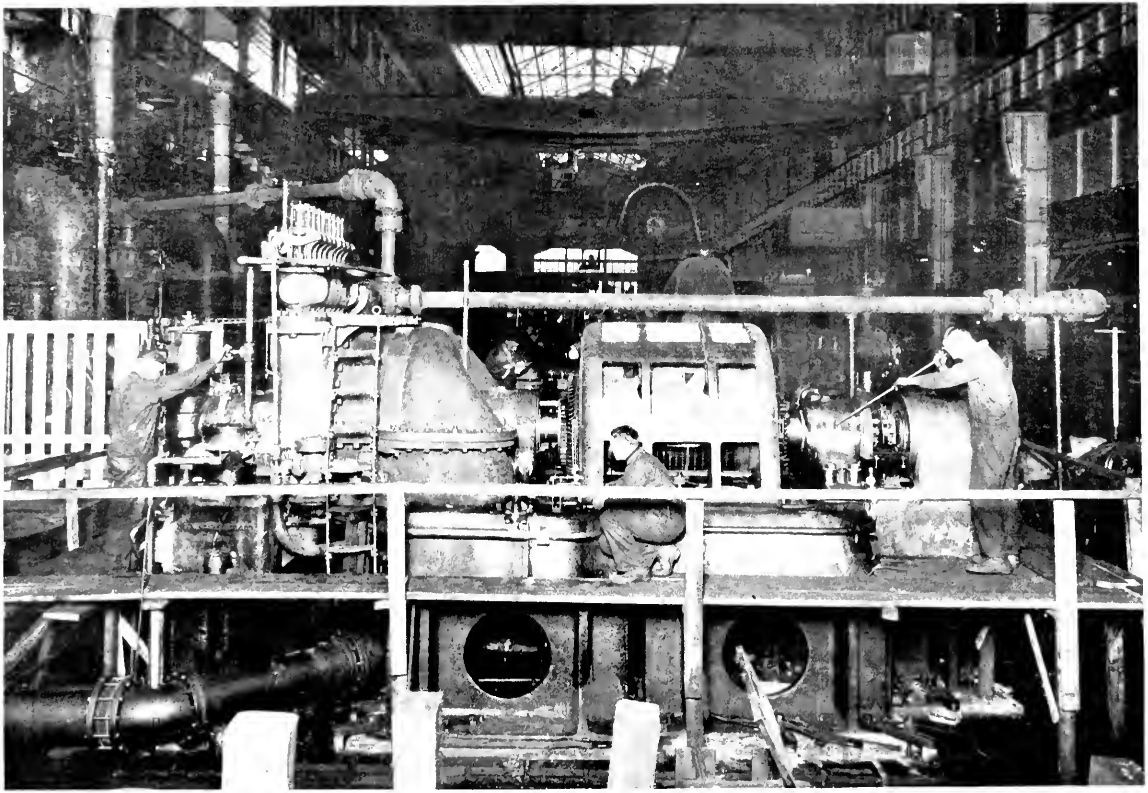


STUDENT ENGINEERS CONDUCTING TEST ON TURBO-GENERATOR SET
See article: The Electrical Testing Course

GENERAL ELECTRIC REVIEW

THE ELECTRICAL TESTING COURSE

Who in the electrical fraternity has held speed on a core loss test, or has "pulled" water boxes on a twenty-four hour heat run, who does not look back on his "test" days with the same pride that he reflects on the years spent at his Alma Mater. Lying flat on his back sanding brushes on the underside of a huge commutator, with carbon dust sifting into his face until he emerges unrecognizable, is not of itself an enviable occupation for a college graduate, but it is by such roads as this that our foremost electrical engineers have arrived at success. Intimate knowledge of detail in construction and operations is the *sine qua non* of the real engineer, and a qualification that can be acquired only by close association with the practical, or shop side of the industry.

How many engineering undergraduates, now shortly to receive their diplomas, realize the value of this kind of training? Rather, isn't the general frame of mind of many of these young men one of complacent self-sufficiency for the life tasks ahead—a not unnatural result of four to six years of intense study, constituting the period in which the knowledge increment is usually greatest. To these young men especially we refer the article in this issue on the Electrical Testing Course of the General Electric Company.

The great value of this training in fitting the young engineer for the duties of his profession can be best emphasized by a survey of the careers of those men who have made good. It is perfectly right to assume that the membership of the A.I.E.E. embraces the most prominent electrical engineers in the country. By checking the list of former G.E. test men against the A.I.E.E. Blue Book, it was found that approximately one thousand ex-test men are members of the National Body of the Institute, among whom are many high officials in our large corporations—presidents, vice-presidents, general managers, and superintendents. The members of the Institute number approximately 8000, and to some of our readers the proportion of ex-test men may seem small, but it should be remembered that our list includes the graduates of only one manufacturer's test course, although the largest. What percentage of the Institute membership is composed of men who have undergone this splendid training in plants of other manufacturers than the General Electric Company can be only roughly guessed; but the extent to which the investigation was carried by our contributor clearly indicates that the Test is the popular path between college and business by which the college graduate may most profitably enter the electrical field, whether his intention is ultimately to become a designing, commercial, or consulting engineer, or whether he has in mind research or educational work in the industry.

This method of training young men for special positions in the electrical industry had its inception in the pioneer days of the industry at the plant of the Thomson-Houston Company, Lynn, Mass. In those days graduates in electrical engineering did not exist, and men for the test room were chosen from all walks of life, chiefly young mechanics who showed ability and were interested in what seemed to be a promising new field. The product of the company for the first few years was arc dynamos, arc lamps, and accessories of arc lighting installations, and the entire practical experience of the test men was confined to this apparatus.

The value to the organization of this specially trained corps of men was quickly demonstrated, and from the beginning the management has maintained the personnel of the Test on the highest plane by drawing on the most promising sources for recruits—today, the graduating classes of our engineering colleges. Hence we find the testing force composed almost entirely of these young men.

From the student's standpoint the Test offers the best opportunity for rounding out his engineering education with valuable practical experience; and to the Company it provides a ready source from which to build and maintain its organization. A mutual advantage, therefore, exists that is unique in industry

Ventilation Systems for Steam Turbine Alternators

By E. Knowlton and E. H. Freiburghouse

Alternating-current Engineering Department, General Electric Company

Part I. THE DESIGN OF THE VENTILATING SYSTEM

More and more are engineers obtaining greater effort from a pound of material in engines, whether impelled by gas, steam, or water power. In the highly developed airplane engine a horse power is obtained from every two pounds of weight, while in our present turbo-generators as much as six times, or possibly more, power is got from a pound ot material as in the first large units. This, of course, means that proportionate quantities of heat must be dissipated per pound of material, and to prevent serious rises in temperature special means of cooling are necessary. For turbo-generators some sort of forced ventilation is usual. This article describes such a system, in which are incorporated those features which a thorough study of the subject has shown to be desirable.—Editor.

Evolution of the Ventilating Problem

The change from reciprocating drive to turbine drive for alternators resulted in a great increase of power output per pound of material, due to the higher operating speed.

During the development of turbine-driven alternators changes in design were made which permitted additional power output per pound of active material. These changes in design which affected the ventilation involved the losses to be dissipated per unit weight of active material, distance in iron or insulation through which heat must be transmitted, the amount of surface exposed to the cooling air, and the quantity of air flowing through the generator.

Radical changes of this nature were made when the vertical alternator having many poles was superseded by the high-speed horizontal generator having greater length in proportion to its diameter.

The lower speed of engine-driven and vertical turbine-driven alternators was not, however, alone responsible for the greater weight per kilovolt-ampere output. The capacity of alternators designed some time ago was limited more by requirements for close voltage regulation than by dangerous heating. Although there is a value of voltage regulation which must not be exceeded for machines carrying loads of variable impedance, still it is advisable to design alternators away from close regulation, in order to secure greater power per pound and better instantaneous short-circuit characteristics. Naturally, the losses in the alternator per pound of generating material have been correspondingly increased, thus making more difficult the problem of ventilation in machines and station. Some conception of this change in ventilation requirements may be gained from Table I, in which is given the rating in kv-a, the speed, and the relative losses per pound of active material, assuming the losses for the slow speed alternator as unity.

TABLE I

Kv-a	R.P.M.	Relative Losses per Pound of Active Material
7500	97.3	1
18750	720.0	4
25000	1800.0	6

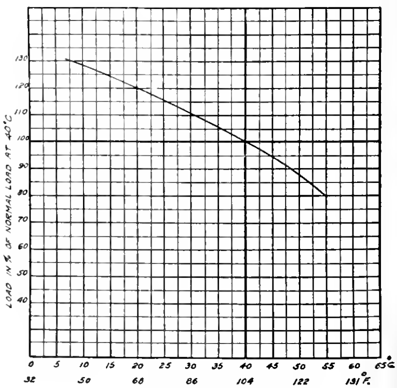


Fig. 1. Capacity of Turbo-alternator as Affected by Temperature of Entering Air

Effect of Temperature on Life of Alternator

Excessive temperature shortens the life of insulating material, decreasing it in proportion to the excess of temperature and the time during which it is maintained. All breakdowns of insulation are not due to temperature, or even to excessive temperature; but to insure against those that are caused by excessive temperature and dirt it is necessary to secure an ample supply of cool, clean air.

Load as a Function of the Temperature

A curve giving the per cent of rated load on turbine alternators as a function of the temperature of the entering air is shown in Fig. 1, which applies to the present design of horizontal solid rotor alternators. The load is based on a given maximum temperature attained by any part of the windings. Since 40 deg. C. is the chosen standard air temperature for electrical machinery, the load at this temperature has been taken as 100 per cent load. The air discharged from a turbine alternator must not be permitted to recirculate through the machine unless some means is provided for removing the heat, otherwise its temperature will rapidly increase. This may be shown by an assumption. Three 25,000 kilovolt-amperes turbine alternators requiring a total of 165,000 cu. ft. of air per minute would fill a station having dimensions of 50 ft. by 72 ft. by 150 ft. with air in less than three and one-half minutes. If the losses were 2.5

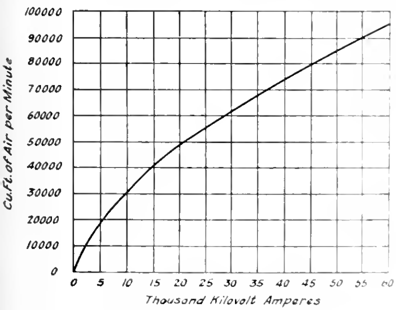


Fig. 2. Quantity of Air Required by Turbo-alternators of Various Capacities

per cent, enough heat would be discharged in ten minutes to raise the temperature of the station air 30 deg. C. even if 50 per cent of the heat were lost by way of doors, walls, etc. Since the permissible load on a turbine alternator depends in part upon the temperature rise of the ventilating air, the question is often asked whether the humidity of the air should be taken into account. The question is based on the knowledge that water vapor has a higher specific heat than air, and it is assumed that the more water vapor in the mixture the greater is its specific heat. This is true, but the quantity of water vapor, even in a saturated mixture, is too small to have an appreciable effect on the thermal capacity of the mixture.

As an example, consider the mixtures of air and water vapor, A, B, and C, Table II, each having a volume of 100 cu. ft. and relative humidities of 100 per cent, 50 per cent, and zero per cent. Sample A is saturated with water vapor, sample B has one-half as much water vapor as sample A, and sample C is absolutely dry, having no water vapor.

TABLE II

THERMAL CAPACITY OF AIR HAVING VARIOUS AMOUNTS OF WATER VAPOR

The calculations are on the basis of, Original temperature	32.2 deg. C. 90 deg F		
Rise in temperature of the mixtures	20.0 deg. C. 36 deg. F		
Final temperatures	52.2 deg. C. 126 deg. F		
Specific heat of air	0.2379		
Specific heat of water vapor	0.475		
Sample	A	B	C
Relative humidity	100%	50%	0%
Weight of dry air in mixture, lb.	6.896	7.067	7.22
Weight of water vapor in mixture, lb	0.212	0.106	0.00
Weight of mixture	7.108	7.173	7.22
B.t.u. to raise air 36 deg. F. (20 deg. C.)	59.06	60.52	61.83
B.t.u. to raise vapor 36 deg. F. (20 deg. C.	3.63	1.815	0.00
B.t.u. to raise mixture 36 deg. F. (20 deg. C.)	62.69	62.335	61.83

The last items in the table show that the energy absorbed by the saturated air is only $1\frac{1}{2}$ per cent greater than the energy absorbed by perfectly dry air.

Quantity of Air

The quantity of air required for cooling a generator depends on several factors in design, but in general it varies approximately with the total losses of the machine minus those in the bearings. For reasons already given, the heat losses per unit of surface which must be carried away are relatively greater in the present than in the older turbo-alternators. A system of forced ventilation is absolutely necessary, since the natural [illegible] of an alternator having a solid forged rotor is negligible. The efficiencies of large capacity alternators are considerably higher than those of small sets and on this account, the quantities of air per kilovolt-amperes are smaller for the former than for the latter. Fig. 2 shows the approximate quantity of air required by steam turbine alternators of capacities ranging from 1000 to 50,000 kilovolt-amperes.

Control of Ventilation

If a generator were operated by taking air from and delivering it to the room without some arrangement for removing heat from the air, the permissible load would be rapidly reduced, as seen from the load temperature curve. The ventilation arrangement shown in Fig. 3 is recommended. This is such that the air passing through the generator may be admitted and discharged wholly outside the turbine room, or wholly inside; or partly inside, and partly outside. This allows considerable control of generator and turbine room temperatures throughout the year. In hot weather the air to the generator may be admitted from and discharged outside the turbine room, and the room itself cooled by opening windows and doors.

During the coldest weather the air that is passed through the generator may be admitted from and discharged inside the station. Between these extremes it may be advisable to take part of the air from the station and part from outside, and discharge it in a similar manner.

Dampers

In Fig. 3, are shown various dampers for controlling the proportioning of air into and from the generator, as described above. A fire damper is indicated in each of the intake and discharge ducts, located as close to the generator as conditions will permit. The control of these two dampers should be positive, handy, and quickly actuated in case of fire within the generator, thus smothering the fire with the least amount of combustion. After the dampers have been closed steam may be very effectively used for quenching the fire.*

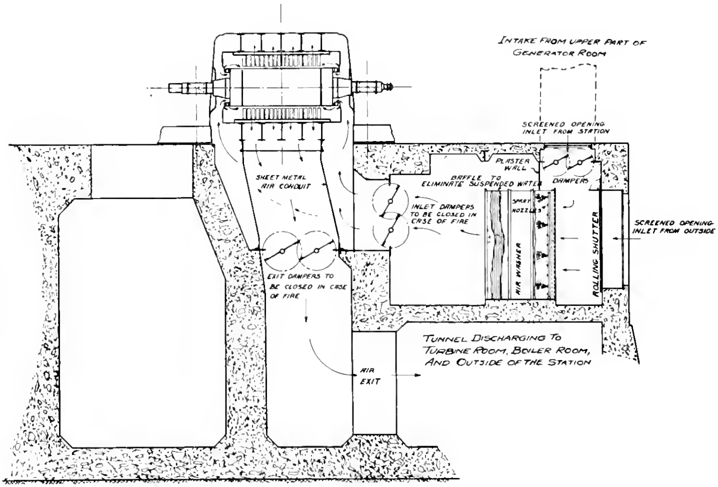


Fig. 3. Diagram of a Ventilation System for Turbo-alternator

Discharge of Air to Boiler Room

The question of preheating the air used in combustion is being seriously considered, and to obtain this effect in part the heated air discharged from the alternator could be used. In some installations, this is being done and considerable saving in fuel secured. There are no objections to this arrangement, unless it involves restrictions or excessive length in the air discharge duct which would impose too great a duty upon the fans and

* See Article by M. A. Savage, GENERAL ELECTRIC REVIEW, January 1918.

thus curtail the supply to the alternator. The volume of air supplied by the generators varies from 25 to 60 per cent of the total quantity required by the furnaces.

Design of Station Air Ducts

If there is a basement under the engine room the ducts may be made of sheet iron and suspended from the basement ceiling. The design of the station air ducts should be carefully studied in order not to impose too great a duty on the fans of the rotor or on independent blowers.

Too great a resistance to air flow in the ducts will materially reduce the quantity of air and possibly defeat the purpose for which the ducts are installed. The resistance of air ducts is dependent on (a), the change in direction and cross-section; (b), the condition of the surface of the ducts; and (c), the superficial area of the duct per unit of length, which takes into account the fact that for the same area of cross-section a round or square section has less friction than a rectangular section. Unless the deviation is great it may be neglected.

Air moving in a duct exerts a certain pressure (impact head) on a plane at right-angles to its path, and a different pressure (static head) on a plane parallel to its path. The difference between the two is the pressure (velocity head) due to the velocity of the air. If the duct is uniform in cross-section the velocity of the air and the velocity head do not change, but the impact head and the static head decrease by the same amount in the direction of the flow of air, due to the friction of the sides of the duct and to the friction of the eddy currents in the air.

The pressure of air is usually measured in inches of water. This is conveniently accomplished by having a glass U-tube partly filled with water and each leg connected to the two points between which it is desired to know the difference in the pressures. The difference in the water levels in the two legs gives the difference in pressure desired. Pressure is usually required between a certain point and the atmosphere, and for such a measurement one leg of the tube is left open.

Let V = Velocity of air in ft. per min.

H_v = Velocity head in inches of water.

$$H_v = \left(\frac{V}{4000}\right)^2$$

Therefore

$$V^2 = 16,000,000\, H_v \qquad (1)$$

Since the drop in pressure of air passing along a duct is dependent on the velocity of the air, it is convenient to consider this drop in terms of H_v (velocity head). Experiments have given the following results for sheet metal duct.

Let H = loss of static head, in inches of water due to friction

V = (as before) velocity of air in ft. per min.

h = greater dimension of rectangular duct cross-section, in feet.

w = lesser dimension of rectangular duct cross-section, in feet.

L = length of duct in feet.

For a sheet metal duct of rectangular cross-section

$$H = \frac{V^2 L}{1250 \times 10^6} \cdot \frac{h + w}{hw} \qquad (2)$$

For a round or square sheet metal duct of diameter h

$$H = \frac{V^2 L}{625 \times 10^6 h}$$

Substituting the value of V^2 given in (1)

$$H = \frac{H_v L}{39\, h} \qquad (3)$$

This means that in a round or square sheet metal duct the loss in static head due to friction in a length of 39 diameters is equal to the velocity head of air. The friction of concrete ducts is about 50 per cent greater than that of sheet metal, and formula (3) becomes

$$H = \frac{H_v L}{26\, h} \qquad (4)$$

Experiments have also shown that a right-angle turn with an outside radius equal to the diameter results in a loss of static head equal to the velocity head. The loss in static head due to leaving a large chamber is also equal to the velocity head in the duct.

To estimate the loss in static head in a round or square sheet metal duct.

Let

H_v = the velocity head

a = the number of right-angle turns

[illegible] = the number of abrupt reductions in area

[illegible] = the length of duct ÷ diameter of duct

The loss in static head is

[illegible]

This is the difference in pressure (expressed in inches of water) necessary to pass the air through the duct.

For the average installation a velocity of 1500 ft. per min. does not require too large a duct nor does it impose too great a duty on the air moving apparatus. This gives a velocity head of

$$H_v = \left(\frac{1500}{4000}\right)^2 = 0.14 \text{ in.}$$

If a duct had three right-angle turns, two abrupt reductions in size, and was 42 diameters long, the pressure necessary to pass air through the duct at this velocity would be equal to

$$\left(3+2+\frac{42}{39}\right) 0.14 = 0.85 \text{ in.}$$

In a properly designed air washer the pressure necessary to overcome the resistance to the air in passing through the spray and eliminators should not exceed 0.375 inches of water. Including this resistance the total pressure to carry air through the external ducts and air washer is 1.225 inches.

If the speed of the fan and the resistance of the air circuit is fixed, the volume of air and the pressure developed by the fan are also fixed. Moderate proportional increases in the resistance of the fan circuit do not appreciably affect the pressure developed by the fan, but part of the pressure is used in passing air through this additional resistance. For moderate proportional changes in resistance the volume of air may be taken as proportional to the square root of the ratio of pressure available to pass a given quantity of air through the generator alone under the two conditions. For instance, consider a case where a certain machine has no external duct and the fan produces eight inches pressure and passes through the machine 10,000 cubic feet of air per minute. Assume that there is added an external duct and air washer in which the total head lost is 1.225 in. The quantity of air under the second condition is closely given by

$$Q = \sqrt{\frac{8-1.225}{8}} \times 10{,}000 = 9200 \text{ cu. ft. per min.}$$

The air washer alone reduces the amount of air which would have otherwise passed through the ducts and the generator by 2.5 per cent, and the ducts account for 5.5 per cent. If the fan produced the movement of air with a pressure of 3 in. the volume would be

$$Q = \sqrt{\frac{3-1.225}{3}} \times 10{,}000 = 7700 \text{ cu. ft. per min.}$$

In the first case the reduction in volume of air was 8 per cent, and in the latter case 23 per cent.

The turbine alternator manufacturer takes into account the fact that the station air ducts and air washer are desirable and makes allowance for such resistance. However, if the ducts contemplated are unusually long, small in cross-section, or have a large number of elbows or abrupt changes in cross-section, the manufacturer should be consulted.

If changes cannot be made in the contemplated design of the ducts to secure lower resistance, it may be necessary to install a blower external to the generator, since but little additional pressure can be secured by changes in the design of the fans on the generator.

Effect of Dirt on Temperatures

If the generator air passages are allowed to become filled with dirt the utility of properly constructed ducts will be defeated.

There are little data available on the difference in the operating temperature between a clean and dirty machine, but it is known that dirt soon collects in the air ducts and over the windings, greatly reducing the effectiveness of the air as a cooling medium. Such an accumulation is particularly rapid where any oil vapor is drawn into the alternator by the ingoing air. The result of the two tests on machines in commercial service follow. The loads were the same under both conditions:

	Dirty	Clean
Machine 1, rise of armature winding	54	37
Machine 2, rise of armature core	54	41

Clean air may be obtained by passing it through cloth screens; however, it is far preferable to use an air washer which both cleans the air and reduces its temperature.

Air Washer, or Humidifier

These names briefly describe an apparatus for cleaning and humidifying the air. It consists of a chamber for housing a very fine spray of water and a series of eliminator plates for removing the free moisture and dirt from the air after passing through the spray of water. It is quite important that all free or entrained water be removed from the air before leaving the washer. If the water used in producing the spray is recirculated, the water as well as the air will be brought to the wet bulb temperature of the entering air. The amount that the air is reduced in temperature depends upon its humidity before it enters the washer. If the air is saturated before entering, it is obvious that there will be no evaporation and no reduction in temperature. As an example of temperature reduction, consider the conditions which prevailed in New York at 3 p.m., July 9, 1912. These conditions are selected, as they give the maximum reduction in temperature during the months of July and August of that year.

Entering air at............96 deg. F. (35.6 deg. C.)
Relative humidity..0.39

Under these conditions the air would leave the humidifier with 100 per cent humidity, i.e., saturated with water vapor, and theoretically the temperature of the air leaving the washer should be 76 deg. F. (24.5 deg. C.). Actually it will be slightly higher, but 2 deg. F. is ample allowance. The air, therefore, would be at a temperature of 78 deg. F. (25.6 deg. C.). With the water circulated in the system as is customary it also maintains a temperature of 78 deg. F. (25.6 deg. C.).

Reference to Fig. 1 shows that the relation of the loads under the two conditions is

With air washer.....	1.14 per cent	of permissible load with 40 degree C. entering air.
Without air washer..	1.04 per cent	

Under the most adverse conditions which have been recorded in New York City for several years, the maximum exit temperature of air from a properly designed and operated air washer would not exceed 82 deg. F. (27.8 deg. C.). Reference to Fig. 1 shows that the load for this temperature is 112 per cent of the load at an air temperature of 40 deg. C. This is the minimum load based on a safe operating temperature which it would have been necessary to carry in New York City at any time during several years with an air washer in operation.

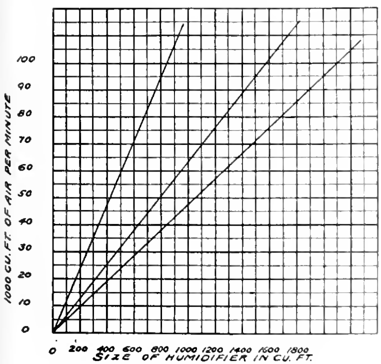


Fig. 4. Sizes of Air Washers for Various Quantities of Air

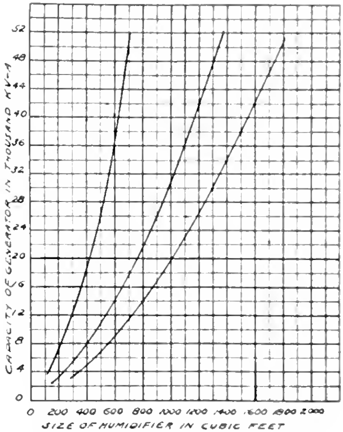


Fig. 5. Sizes of Air Washers for Turbo-alternators of Various Capacities

In other localities than New York City the conditions differ, and more or less benefit will result. In Table IV is given the average reduction in the temperature of the air and generator which may be obtained with and without the use of an air washer. This covers the months of June, July, and August, 1911 and 1912. It should be noted that Table IV represents average conditions. There are times when the gain is much larger. This is shown by comparing (for New York City) the average values in Table IV with the maximum values for 3 p.m., July 9, 1912. This comparison is given in Table V.

Figs. 4 and 5 are included to show the sizes of air washers made by three different manufacturers for various amounts of air and capacities of alternators.

The energy loss due to the resistance of the air in passing through a washer varies as the square of the velocity of the air. If the velocity of the air in the washer is 500 ft. per minute, this loss will be approximately 0.05 kw. per 1000 cu. ft. of air per minute. For any given design of washer the velocity of the air through the washer should not equal [illegible] which would cause suspended water to be carried by the air from the washer into the generator.

Overload Capacity of Old and Modern Turbine Units

The early steam turbines could supply power greatly in excess of their rated capacity and the permissible load of the set was dependent on the generator temperatures. The reduction in temperature of air secured by the use of an air washer, therefore, made it possible to carry part or all of such overloads on the generators of these sets with the same copper temperature as obtained for normal load and no washer in use. But these conditions do not exist with the modern steam turbine sets, as will be explained.

TABLE IV

REDUCTION IN TEMPERATURE OF AIR OBTAINED BY THE USE OF A HUMIDIFIER

Reduction in temperature of air and generator by the use of an air washer; also, gallons of water evaporated per thousand of cubic feet of air.

Average values for the months June, July, and August, years 1911 and 1912.

	Without Air Washer	With Air Washer	Reduction in Generator Temp. C°.	Gallons of Water Evaporated Per 1000 Cu. Ft. of Air
	Air Entering Deg. C.	Air Entering Deg. C.		
San Francisco, Cal.	13.6	11.7	1.9	0.0083
Bismark, N. D.....	19.1	15	4.1	0.0173
Jacksonville, Fla..	26.7	23.6	3.1	0.0108
Albany, N. Y....	20.3	16.6	3.7	0.0144
Boston, Mass...	21.4	17	4.4	0.0182
Chicago, Ill......	22.3	17.8	4.5	0.0176
New York, N. Y.	22.8	18.2	4.6	0.0186
Indianapolis, Ind..	23.4	18.2	5.2	0.0214
San Antonio, Texas	28.8	22	6.8	0.0283
Phœnix, Ariz......	30.8	19.2	11.6	0.0468

In 1914 the American Institute of Electrical Engineers adopted a continuous maximum rating for turbo-alternators based on safe operating temperatures when the entering ventilating air is at a temperature of 40 deg. C. The capacity of the steam turbine is predetermined with far greater accuracy now than formerly, and the set cannot be so greatly overloaded. The capacity of a clean generator is no longer dependent on temperature, provided the ventilating air is considerably below 40 deg. C. (as is usually the case) for before the full benefit due to the lower air temperature could be realized the capacity would be limited by other factors.

Present Usefulness of an Air Washer

When operated with the modern steam turbine unit the principal usefulness of an air washer is the elimination of dirt. This is of extreme importance. Without a washer the air ducts in the generator become clogged with dirt, which reduces the quantity of air and renders the remainder less effective because of the high heat insulating qualities of the dirt. The effect is cumulative and may in a comparatively short time reach the stage where the capacity of the unit is limited by the temperature of the generator. Dirt around a steam station is liable to contain more or less coal dust which, when deposited on the end windings and connections, forms a conducting path to ground, thereby imposing dielectric stresses on the weakest parts of the insulation.

TABLE V

A COMPARISON OF THE AVERAGE CONDITIONS IN NEW YORK CITY FOR JUNE, JULY, AND AUGUST, 1911 AND 1912, WITH THE MAXIMUM CONDITION OF JULY 9, 1912.

	Without Air Washer	With Air Washer	Reduction in Generator Temperatures C°.
	Air Entering Deg. C.	Air Entering Deg. C.	
Average	22.8	18.2	4.6
Maximum	35.6	25.6	10.0

Briefly, a washer should be used to prolong the life of the generator by providing cool clean air which carries no free water. The prevention of free water in station and generator will be discussed at length in Part II of this article.

Methods for More Efficiently Utilizing Our Fuel Resources

PART XV. ABSORPTION METHOD FOR EXTRACTING GASOLENE FROM NATURAL GAS

By George A. Burrell, P. M. Biddison, and C. G. Oberfell

United States Bureau of Mines

Bulletin 120 of the United States Bureau of Mines, "Extraction of Gasolene from Natural Gas by Absorption Methods," which has recently been issued, contains the following summary of data regarding the process.—Editor.

The absorption method of extracting gasolene from natural gas consists in bringing the gas in contact with an oil heavier than gasolene, such as a petroleum distillate of about 34 deg. B., to absorb the gasolene from it, and then separating the gasolene from the oil by distillation. The oil is used simply as a carrier of the gasolene from the absorption tank to the still, and may be used over and over again.

In plants using compression and condensation methods only, casing-head natural gas that is comparatively rich in gasolene vapor carrying upward of three-fourths of a gallon of gasolene per 1000 cubic feet of gas is treated, whereas so-called "dry" natural gas, such as is used in cities, towns, and factories for heating, lighting, and other purposes, can be treated by the absorption process. In 1914 about 591,000,000,000 cu. ft. of this kind of natural gas was used in the United States. Most of this natural gas carries as much as 1 to 2 pints of gasolene per 1000 cu. ft. of gas. Probably 75,000,000 gal. of gasolene per year could be recovered by passing the gas through absorption plants before it is marketed. It is also true that casing-head gas that is too lean to treat by compression methods can be treated by the absorption method.

Advantages of Extracting the Gasolene

The removal of the gasolene does not reduce the heating value of the gas to an appreciable extent. In the case of natural gas from two particular fields, extracting the gasolene lowered the heating value only 3 per cent in one case and 2.2 per cent in the other.

A further advantage of the process, apart from the value of the gasolene recovered, lies in the fact that gasolene if left in the gas lines destroys the rubber in pipe couplings. The cost of replacing these rubbers and repairing broken connections, and the resulting loss of natural gas, has been a large item of expense in the operating costs of gas transportation companies.

The importance of the absorption process of extracting gasolene from natural gas increases with the demand for gasolene. The method is practically identical with the process of extracting benzol and toluol from coke-oven gases. A difference lies in the fact that coke-oven gases are treated at about atmospheric pressure, whereas much natural gas must be treated at pressures as high as 200 to 300 lb. per square inch, because it is not desirable to disturb the carrying system.

As nearly as can be determined the first large-scale installation for extracting gasolene from natural gas by the absorption process at high pressure was constructed at Hastings, West Virginia, in 1913. The plant was built following experiments by G. M. Saybolt, of the operating company.

Testing the Gas

Two methods can be used in testing natural gas as regards the practicability of extracting gasolene from it by the absorption process. In the laboratory method the gasolene is frozen out of the natural gas and its pressure and volume determined. In the field method, a small absorber and a gas meter are taken to the well or pipe-line to be tested for natural gas, the gas is passed through the absorbent oil, and the extracted gasolene is distilled from the oil. The results duplicate on a small scale those in a commercial plant.

All natural gas except that which contains methane as the only combustible gas, contains gasolene vapor. However, in gas from some wells the gasolene content may be small. This is sometimes because the gas is under high pressure, and the gasolene vapor because of its greater density at this high pressure is not produced in quantity until the pressure is relieved. But even high-pressure wells represent potential sources of gasolene supply in that the gas will carry commercial quantities of gasolene vapor as the pressure declines.

Experimental Work

Tests on natural gas from two different fields reported in the bulletin* showed 1 pint and 1.5 pints, respectively, of gasolene per 1000 cu. ft. About 50,000,000 cu. ft. of natural gas per day was available for treatment.

The oils used in the experiments to absorb the gasolene were petroleum distillates that had a specific gravity of 35 deg. B., and which started to boil at 400 to 482 deg. F. It is necessary that the boiling point of the oil used be much higher than the boiling point of the gasolene to facilitate the extraction of the latter by distillation.

Tests were made with a plant of fairly large proportions, capable of handling 15,000 to 30,000 cu. ft. of gas per hour. The principal features of the plant consisted of an absorber where the natural gas and absorbent oil were brought in contact with each other, a heat exchanger where the oil with its absorbed gasolene was heated before going to the still, a steam still where the gasolene was extracted from the oil, a cooler where the hot oil from the still was cooled before receiving another charge of gasolene, pumps, and a weathering tank.

Several different types of absorbers were tried. The one giving the best results consisted of a tower filled with pebbles, in which the oil flowed downward and the gas upward.

An increase in the temperature of the oil in the absorber from 75 to 85 deg. F. lowered the gasolene yield about 0.3 pint per 1000 cu. ft. of gas. An increase in the pressure of the gas from atmospheric pressure to 110 lb. per square inch increased the yield from 0.7 pint to about 2 pints of gasolene per 1000 cu. ft. of gas.

The gravity of the gasolene obtained varied between 77 and 85 deg. B. The boiling point ranged from 80 to 300 deg. F. The evaporation-loss was about 11 per cent in 24 hours as compared to 2.4 per cent from a "straight" refinery gasolene having a gravity of 60.4 deg. B. The vapor pressure of the gasolene ranged from 1 lb. at 70 deg. F. to about 5 lb. at 100 deg. F. This is important because it shows that the gasolene can be safely shipped in tank-cars.

* Bulletin 120, "Extraction of Gasolene from Natural Gas by Absorption Methods," United States Bureau of Mines.

The Field for the Absorption Process

The absorption process can be profitably operated at low pressures.

As good results can be obtained from casing-head gas with the absorption process as with the compression process. However, where the residual gas from the plant has to be forced into a pipe-line at high pressure there is no advantage in installing an absorption plant, because a compressor would be needed anyhow.

A promising field for the absorption process lies in the treatment of gas from oil-wells producing from a sand into which air has been forced under pressure to increase the oil production. This gas, as it flows from the wells, can be treated by the absorption process and the gasolene it contains extracted.

The amount of power required for the operation of an absorption plant will vary from 0.018 to 1.443 boiler horse power per 1000 cu. ft. of gas treated per hour for gas containing 0.0625 to 5 gal. of gasolene per 1000 cu. ft., and the amount of water from 1.46 to 116.8 gals. per 1000 cu. ft. of gas. The rate of flow of the absorbing oil will vary from 6 to 60 gal. per 1000 cu. ft. of gas treated per 24 hours, for gas that contains from 1 pint to 2.5 gal. of gasolene per 1000 cubic feet.

A successful use of naphtha as an absorbent for gasolene is found in the absorption in the naphtha of waste gases from compression plants treating casing-head gasolene. Some tests were made in which natural gas was passed into naphtha with a gravity of about 55 deg. B. When the naphtha had absorbed all the gasolene that was desired it was removed and fresh naphtha substituted. The yield of gasolene was 300 to 500 per cent greater than that by the oil absorption and distillation process. In some tests the naphtha, besides being increased in volume owing to the absorbed gasolene, was raised in gravity to 60 or 62 deg. B. An objection to the process lies in the fact that a large amount of naphtha has to be handled—at least seven tanks of naphtha for each tank of gasolene obtained. If the naphtha is permitted to absorb too much gasolene its vapor pressure is raised too high for safe transportation.

There are possibilities in the application of the absorption method to casing-head natural gas, much of which is too lean to be treated by compression and condensation methods.

PART XVI. THE MANUFACTURE OF GASOLENE FROM NATURAL GAS*

By J. C. McDowell

In General Charge of the Doherty Oil and Natural Gas Properties

Natural gas is one of our important fuel resources. This article reviews the natural-gas industry, and the processes which have been introduced in recent years to extract valuable condensates. These are blended with heavy naphtha in order to increase the production of gasolene.—Editor.

The petroleum industry is a development of the present generation. The man is yet living in Pittsburgh who purchased the first tract of land on which to drill for petroleum, upon the completion of the Drake well, near Titusville, Pa., in 1859. A small refinery was in operation in Pittsburgh prior to the completion of the Drake well, however, running on crude oil obtained from wells drilled and operated for salt near Tarentum, Pa. The Drake well has been recognized as the pioneer well, probably because it was the initial venture undertaken solely for petroleum.

From the small beginnings of Oil Creek days in the 'sixties, the business has grown until its magnitude and importanee attract general attention and increasing popular interest. The wide geographical range of its deposit, the element of risk and romance in its discovery, interesting tales of fabulous fortunes grasped in a day, of hopes deferred, hearts made sick, and final financial ruin in the quest for oil, are some of the features of public interest. But the real reason for the popular interest in the petroleum industry is that the products of petroleum have such an important place in every industry and every household, contributing largely to the necessities and pleasures of humanity in every grade of life, and dwellers in the remotest regions of the earth are touched by it through the energy of the men engaged in its trade.

The development of another youthful industry—the automobile and internal combustion engine—has revolutionized the oil industry and created a new and vital interest in it. Less than twenty-five years ago gasolene was a by-product of the refinery, difficult to dispose of at any price. Now the industry is taxed to its limit by the demand for motor fuel (gasolene) and lubricating oil, and it is a subject of general concern from what source the ever growing requirements for these products are to be supplied.

Natural Gas

From the beginning of the oil industry, gas in more or less quantity has been found in petroleum deposits and produced along with oil, and many wells drilled for oil produced gas only. Prior to about 1880 but slight use was made of the gas other than to use it for fuel in boilers, and some use was also made of it for domestic fuel in dwellings on the lease. The great bulk of it, however, was wasted, its presence being a nuisance to the operator.

About 1880 the qualities of natural gas as fuel began to be appreciated and the natural gas industry began. Its growth, slow at first, soon attained importance. The invention of the automatic pressure regulator, the rubber coupler joint (permitting the use of pipe of large diameter and consequent capacity), the gas compressor, and improved methods of combustion soon greatly enlarged the area of its profitable distribution, the cost of transportation, and the safety of its use. At the present time it is one of the great industries of the United States and Canada, with an investment exceeding $350,000,000 and an annual income of over $100,000,000. It has grown with accelerated speed, 1916 being the year of maximum production and earnings.

Natural-Gas Gasolene

Although it has been known from the early period of the oil industry that under some conditions light gravity condensates were recoverable from natural gas, it is within the last few years, since gasolene became of great commercial importance, that this branch of the petroleum and natural-gas industry began to be developed.

In the gasolene industry, natural gas is classified in two divisions "wet" gas and "dry" gas. Gas produced from the same sand as oil is known as wet gas, while gas produced from strata (sands) that produce gas only is termed dry gas. Yet there is no clear line of demarcation between so-called wet gas and dry gas. When a well is first drilled, the quantity of gas escaping with the oil is frequently great, the gas flow in time diminishing. When gas comes with the flowing oil the two can be separated by a gas trap and plants are frequently erected to extract gasolene from this wet gas. Oil wells that have ceased

* From the *Doherty News*, September 1917, p. 5.

flowing and are being pumped, usually continue to produce much gas at the casing head. It is this casing-head gas from which the bulk of natural gas condensate is now being recovered.

Natural gas is a mixture of hydrocarbons of the paraffin series, also usually containing very small portions of nitrogen, carbon dioxide, and water vapors. A sample of wet gas recently analyzed showed the following composition:

Methane	37.4%
Ethane	32.0%
Propane	20.1%
Butane, Pentane, Hexane, etc	10.5%
Total Inc. 1.03 Nitrogen	100.0%

The dry gases are usually very high in methane, sometimes containing as much as 95 per cent. Methane cannot be liquefied by ordinary commercial methods, consequently the gasolene content of natural gas is recovered from the lower hydrocarbons, ethane, propane, butane, etc.

There are two general methods of recovering condensates from natural gas. Briefly, they may be described as follows:

(a) The Compression Method—Compressing the gas by means of an air compressor adapted to the purpose. Cooling the compressed gas by means of condensing coils, by use of water, air, or artificial refrigeration.

(b) The Absorption Method—Passing the gas through towers or receptacles in contact with heavy oils (used as a menstrum); then heating the oil in ordinary stills to a point where the light vapors absorbed by the menstrum pass off as vapors, which vapors are reduced to condensates by the usual methods of condensation.

Compression Process

A plant for recovering gasolene from casing-head gas was erected in the vicinity of Titusville, Pa., near the Drake well in 1904. The equipment was crude. The gas was compressed by gas pumps and condensed by means of a pipe coil in a water tank, the condensate dripping into a wooden barrel. The product, when first obtained, had a gravity of 80 to 90 degrees Baumé scale and the loss from evaporation was large. Other plants were soon installed in that locality. These ventures proving a commercial success, plants of better design and equipment were installed in other oil regions.

At first, ordinary gas pumps at pressures of 50 pounds were used; at present, compressors —usually two-stage—of modern design are installed and the gas is compressed to from 100 to 250 pounds per square inch, depending upon the quality of the gas and the resultant gravity of the condensate.

Speaking generally, the higher the gas is compressed, the higher the resultant condensate. At above 80 degrees Baumé the evaporation of the product at atmosphere is very rapid. The quantity of gas consumed or utilized in the recovery of the gasolene is but a small percentage of the total volume compressed. The waste gas, or gas from which the gasolene has been recovered, can be used for fuel or internal combustion engines. The recovery of gasolene from casing-head gas is from two to eight gallons per thousand cubic feet of gas, depending upon the quality of the gas.

The average compression plant is small, in some instances a plant handling 100,000 cubic feet in twenty-four hours is profitable. A plant passing 2,000,000 cubic feet is considered a large one. The installation of a plant involves connecting up all the wells, from which gas is to be used, by a pipe line system to convey the casing-head gas to the compression plant, as well as suitable tankage and shipping facilities. Several hundred oil wells are sometimes connected in one pipe line system.

Absorption Process

The absorption process is of more recent adoption than the compression process, and is usually installed to recover condensates from dry gas transported through pipe lines to more or less distant markets. The operation is essentially as follows.

The plant is erected close to the pipe line, preferably at a gas pipe-line compressor station. By suitable connections the gas is diverted through the absorbers; the flow of gas through the pipe lines is undisturbed. The gas passes into the bottom of the absorbers, up through the oil and out at the top, and thence on to the market. In passing through the absorber, the gas mingles with the oil coming into the absorber from the top, broken and spread by baffles and other devices. The oil in descending absorbs gasolene from the gas, and is pumped from the bottom into a still where the gasolene is distilled from the oil by live steam. The oil, stripped of the gasolene, is then pumped into the absorber to absorb more gasolene, the operation being a continuous circuit of the heavy oil. A weathering tank is in the circuit to get rid of some of the lighter condensates before the oil enters the still. There is also a heat exchanger for cooling the oil before it returns to the absorber. Recently, some absorption plants are also equipped with a compressor plant which takes the light gases from the weathering tank; and the tail pipe of the condensers reduces them to a liquid and mingles it with the gasolene recovered through the absorber.

The heating value of the gas after passing through the absorber is not appreciably lowered, and the deleterious effect of gasolene on the rubber couplings of the gas pipe line is eliminated.

The recovery of gasolene from dry gas by the absorption method is comparatively small and depends somewhat on the quality of the gas, but is usually about one pint for each one thousand cubic feet.

Absorption plants are usually installed where large volumes of gas can be treated in some cases from forty to fifty million cubic feet in each twenty-four hours.

The Condensate

The term "condensate" is a more suitable name for the liquid obtained from natural gas by either process, for some of the liquid obtained is so volatile that it does not come within the meaning of the trade name "gasolene."

At present, practically all natural-gas condensate is mixed with low-grade naphtha a refinery product—before it is marketed. This process is called "blending."

In the early days of the industry, "weathering" for evaporation of the light vapors of the condensate was necessary for safety in shipping and use. The process of "weathering" frequently caused a loss of from 50 to 75 per cent. By blending, a product is obtained which has a much lower rate of evaporation than the natural-gas condensate, and which can be shipped and used with safety. Several methods of blending are in use. The one in most favor now in the mid-continent field is that of spraying the heavy naphtha into the hot compressed gases as they leave the compressor. Both the naphtha introduced mostly gasified by the heat of the compressed gas and the compressed gas are then passed into the condenser and the resultant gravity reduced to a comparatively stable product.

The use of this method results in a recovery of from 25 to 50 per cent more merchantable product than when the blending is done simply by mixing the condensate and low-grade refinery naphtha.

It is customary to test the gas which it is proposed to treat to determine its gasolene content before installing a plant, and a close determination of the true result can be arrived at by such tests.

Growth of the Industry

The production of gasolene increased from about 400,000 gallons in 1904 to 65,000,000 gallons in 1915. The increase for 1913 over 1912 was 100 per cent. During 1915, 65,364,665 gallons were extracted a gain of 53 per cent over 1914. An average price of 7.9 cents per gallon was received for the unblended product, the value of the year's output being $5,150,823. It is estimated that twenty-four billion cubic feet of natural gas was utilized in the manufacture, with an average recovery of 2.57 gallons of gasolene per thousand cubic feet.

It is estimated that the production of 1916 was approximately 100,000,000 gallons yielding a revenue of over $12,500,000.

Future of the Industry

While every gas well is a potential producer of gasolene, there are many reasons why they will not be utilized for this purpose. Among these reasons are:

(1) Insufficient yield of gas.
(2) Unfavorable location.
(3) Poor quality of gas.

Yet there are many millions of dollars' worth of casing-head gas now going to waste that will be utilized. The time is near when a gasolene plant will be as much a part of a well-equipped oil lease, as the power plant for pumping the wells. The business is profitable, under proper conditions, and conservation is always popular when it is profitable.

Economy of Electric Drive in Cane Sugar Mills

By C. A. Kelsey

Power and Mining Engineering Department, General Electric Company

Last month we published "Electricity in Beet Sugar Factories," by E. M. Ellis; and below we publish a complementary article on electrification of cane sugar mills. It is not a coincidence that electrical operation is most advantageous in both the cane sugar and beet sugar mills; it is simply an added dual example of the fact that electrification of our industries is beneficial. In the present article analysis is made of the general and the specific advantages of electric drive, particular attention being given to the direct-connected motor-driven centrifugal pumps. The fuel requirements of steam and of electric drive are discussed in detail. The advantages and economy of electric drive are further demonstrated with respect to labor, supplies, repairs, production, water supply, illumination, and traction.—Editor.

The prominence of sugar in the list of food products has been accentuated by the war-created shortage of the supply.

The cane sugar industry is perhaps the last of the food industries to adopt electric drive. The reluctance on the part of sugar mill owners to replace their steam-driven pumps and engines by electric motors has been due largely to the process of manufacture and to the employment of unskilled laborers.

As the evaporation of the juice and the concentration to crystal form requires a great amount of heat, and as the exhaust steam from the steam pumps and engines met the steam requirements for heating, the steam drive was considered satisfactory. The introduction of more efficient cane crushing mills and evaporating apparatus and the use of maceration water* rendered steam drive uneconomical because the demand for fuel increased beyond that which could be entirely supplied by the waste cane or "bagasse" that had usually been sufficient. Furthermore, the decrease in net profit realized on raw sugar from year to year compelled a reduction in operating expenses.

A report† issued by the United States Department of Commerce gives details of the cost of producing cane sugar in Cuba, Hawaii, Porto Rico, and Louisiana. This report shows the great variance in the several items of manufacturing cost, which is caused by the different climatic and labor conditions, and manufacturing methods.

The figures applying to Cuba will be compared in this article because of the extent of the Cuban cane sugar industry and the dependence of this country upon Cuba for over half of our sugar supply.

Advantages of Electric Drive

It is not self-evident that sugar machinery can be more advantageously driven by electric motors which receive electric energy from an electric generator which in turn is driven by a steam turbine, than by a steam engine direct. However, a decrease in operating expense and an increased yield results from the use of economical direct motor-driven centrifugal pumps, the electrification of all mechanical drives, and the decrease in the exhaust steam from the centralized power generating equipment.

When the output of a mill is to be increased by equipment of greater capacity, it will be found that this can be accomplished at a minimum cost by the coincident substitution of electric drive. Also, the capacity of the sugar apparatus of a mill can be increased by the changeover to electric drive. To obtain the maximum benefits, however, it is usually necessary to make some slight changes in the sugar apparatus to balance the capacity of the several stations. The saving in operating expense and the increased yield pay for the cost of changing over an existing mill in two or three years.

When a new mill is considered, there are additional reasons for adopting electric drive. The motor-driven machinery costs less, it can be more advantageously placed, it is smaller and lighter, and costs less to install.

The new mills in Cuba and those that have been changed over from steam to electric drive have demonstrated the reliability, economy, and superiority of electric drive.

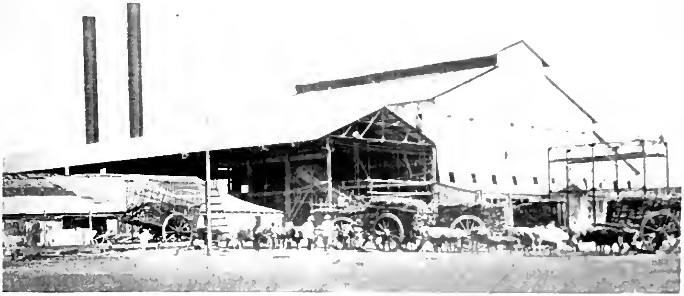
The advantages of electric drive in cane sugar mills will now be considered in detail.

Operation

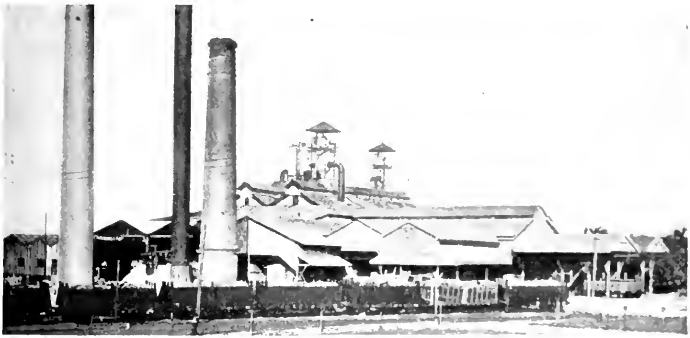
Favorable working conditions in a mill tend to increase the output of the operators and act as an inducement to continuous employment. An electrically driven mill will be cooler, cleaner, quieter, and better lighted than one which is steam driven. In the operation of the pumping, power drives, and the milling plant, the benefits of electric drive are especially pronounced.

* Maceration water is water applied to the cane in its passage through the crushing rolls to assist in the extraction of additional juice containing sugar.

† "The Cane-sugar Industry," United States Department of Commerce, Miscellaneous Series No. 53.



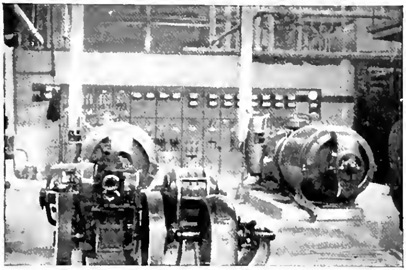
Central Australia, Cuba Erected and Electrified 1915



Central Mercedes, Cuba. Electrified 191[illegible]

El Protrero Sugar Mill, Mexico. [illegible]

Steam engines and pumps require careful handling while starting and constant attention when running. Condensation in the steam line and cylinders will break cylinder heads and pistons unless the pet cocks are opened, the water drained, and the engine or pump brought slowly up to speed. Reciprocating steam pumps will knock when they lose their suction and steam engines which are commonly run without speed governors will race when the load is thrown off. The fluctuating steam pressure will cause proportionate changes in the flow of the liquids pumped and in the speed of the driven machinery. A large number of attendants is required to prevent damage to the pumps and engines and to maintain constant the flow of the material. In order to insure that the pumps will deliver the required pressure



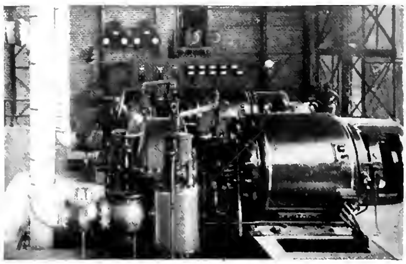
Power Plant, Central Lequeitio, Cuba. Two 300-kw., 480-volt, Alternating-current Curtis Steam Turbines with Oil Engine and Electric Motor-driven Exciters. The Oil Engine Driven Exciter is Used for Lighting in the Dead Season

in the liquid with reduced steam pressure, the steam cylinders are made oversize. Care must be exercised in closing the discharge valves in connection with the throttle valve or a high pressure may form at the liquid end sufficient to blow the packing, start leaks, or even break the pump.

The electric motor requires no careful handling at starting nor attention when up to speed. As the majority of centrifugal pumps and mechanical drives are operated at constant speed, the simple and mechanically strong squirrel cage induction motor is largely used. Motors of five horse power and smaller are started by simply closing a line switch. Larger motors are started by a controlling device having an operating handle with one starting position and a running position.

Where variable speed is required or slow starting is desired or the motor is large compared to the capacity of the power plant, a controller with a number of starting or running points is used. The high starting torque brings the loaded motor rapidly and smoothly up to normal speed. The centrifugal pump is well suited to rapid increase in speed. The pressure at the pump increases with the speed, so that the flow of the liquid is gradually established.

The speed of the constant speed motor does not materially change with a change in load, since it is primarily dependent upon the speed of the electric generator. As the speed of the generator is closely maintained by a sensitive turbine governor, irrespective of changes in load or steam pressure, the speed of the motor-driven pumps and machines



Two 500-kw., 480-volt, Alternating-current Curtis Steam Turbine Generators. Central Agramonte, Cuba

will be constant. The amount of liquid discharged by a centrifugal pump can be closely regulated by throttling the discharge. This does not materially increase the pressure at the pump; in fact, the discharge valve can be entirely closed without producing a dangerous pressure. The power required is proportional to the liquid delivered, so that as the discharge valve is closed the load on the motor decreases. All pumping cannot be done by centrifugal pumps; plunger pumps are more suitable for the scums, massecuites, and molasses due to the viscuous nature of these liquids. The three pistons of the triplex single acting pump produce an approximately uniform crank effort so that the operation is smooth and the flow of the liquid is constant.

When the pumps are electrically driven, the flow of the liquids through the pipes is steady instead of pulsating as with steam pumps. As the friction of liquids in pipes increases with the square of the velocity, a greater average pressure—and therefore power is required of the steam-driven pumps than of the motor-driven pumps.

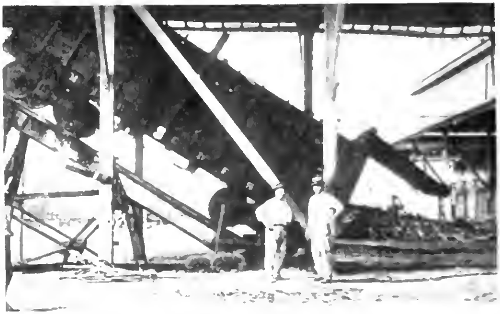
The electric motor is readily adaptable to locations which best suit the pump or driven machine, and the control can be placed to meet the convenience of the operator. The operator need give no attention to the motor in starting; and the pump or driven machine is automatically brought up to normal speed as soon as the controlling device is set at the running position.

Protective devices shut off the electric power in case of overload on the driven machine. The overload devices can be adjusted to operate only after a sustained overload on the motor or to act instantly in limiting the pump pressure. This latter feature finds a valuable application in filter press pumping and results in a considerable saving in damaged plates. Automatic starting equipments start and stop air compressors within specified limits of pressure, and service water tanks can be maintained within given water levels. These devices are not subject to clogging as with similar steam operated devices. Electrically operated brakes are available on drives such as cane hoists or elevators to hold the load from slipping back or for quick and positive stopping.

Grinding Rolls.

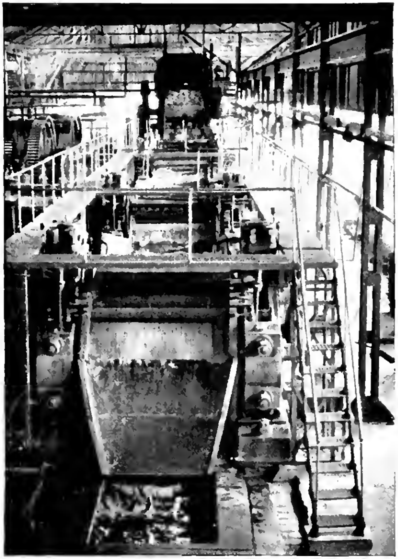
All the problems of power drives in a cane sugar mill find their counterpart in other industries, and they have been successfully solved. While applications closely approximating the power requirements of grinding rolls are numerous in steel, paper, and rubber mills, the methods adopted in these latter industries are not suited to the conditions found in the sugar mill. The motors are idle during the dead season when the atmosphere is hot and damp, and they must operate continuously during the crop under the care of unskilled attendants. The operation of the whole mill depends upon the reliability of the grinding roll drive. The electrical apparatus should, therefore, be simple in design and mechanically strong. Moreover, the initial cost must be in keeping with that of a good steam engine drive. The inherent advantages of the induction motor for all other power applications dictates its exclusive use in the whole mill. The alternating-current speed regulating motor generator sets ordinarily used in steel mills are [illegible] able in sugar mills from the standpoint of cost, of the number of sets required and of their comparative complication.

Motor operated Side Tilting Car Platform, Central Ulacia, Cuba. The control is located on the opposite side with the operator



Hydraulic Car Unloader. Central Mercedes. A motor driven centrifugal pump replaced the steam pump for supplying the water

In order to obtain the maximum capacity and extraction at all times it is necessary to adjust the relative speeds [illegible]. It is also necessary to [illegible] the speed of all the rolls, and to preserve the same relative speeds, to keep [illegible] cane supply [illegible] reduced [illegible] approximately [illegible] normal [illegible] The steam [illegible] satisfactorily meets [illegible] but [illegible] steam consumption [illegible] and [illegible] adjustments



Cane Crushing Rolls, Central Lequeitio

A method of electric drive has recently been developed and built for operation during the present season. It is efficient and simple, meets all the imposed conditions, and includes automatic speed control of the motors to maintain the prescribed relative speeds of the rolls and a variable speed turbine generator to regulate the speed and output of the tandem.

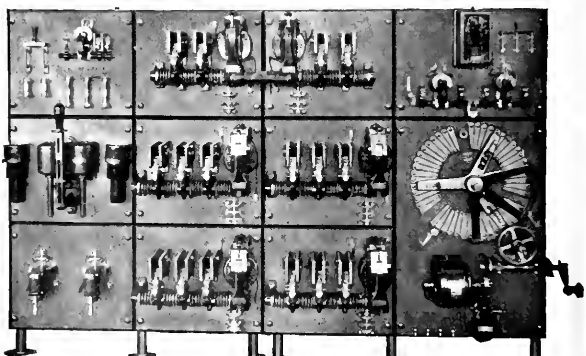
Each motor driving a set of rolls has a speed governor and is served from an individual control panel which contains electrically operated switches for regulating the speed of the motor. Master controllers which control the motors through the panels are grouped at a convenient point on the mill platform and give the operator complete control of the motors, excepting that general speed changes of the mill are made at the turbine governors. The several motors are operated from a turbine independent of the sugar house, and speed changes of the mill will not, therefore, affect the normal operation of the motor-driven pumps and miscellaneous drives.

The control provides one point forward and one point reverse to 75 per cent speed with automatic acceleration, two points forward giving 80 and 85 per cent speed by manual control, and ten points from 85 per cent to normal load speed with automatic speed governing. Automatic control is also included for the two points of manual control, and the master controller can be quickly brought to any desired operating point without overloading the motor. While a range in relative speed is provided up to 15 per cent with normal load torque, it is not expected that all the motors will operate at the same time over this range.

Operation of the whole mill over a range in speed of 30 per cent is obtained by changing the turbine speed, with constant excitation of the generator, without disturbing the relative speed adjustments. Under these conditions the power of the motors varies with the speed; and, as the amount of bagasse is proportional, the power is sufficient at the reduced grinding rate.

Fuel

Rare is the steam-driven mill in which the bagasse is sufficient to evaporate the normal amount of juice and yet give a fair yield. The consumption of fuel additional to the bagasse has been found to be productive of increased profits in a well designed



Main Control Panel for 200-h.p. Variable Speed Induction Motor for Driving Cane Crushing Rolls steam-driven mill. This fuel is required to evaporate the maceration water. The economical proportion of maceration water and hence the additional fuel is dependent upon the market price of sugar and the cost of the coal or wood used.

On the other hand, in a well-designed electrically driven mill, the bagasse is more than sufficient to evaporate the normal juice and the maximum effective degree of maceration water can be applied, which results in a high yield. Uses can be found for the excess bagasse in the operation of remote pumping plants, lighting the adjacent town, or for electric traction around the mill. The bagasse becomes sufficient due to the reduction of the total power required, the decrease in the amount of steam required per horse power of work, the smaller radiation and leakage losses, etc.

It has been demonstrated that power can be generated by a large steam turbine, transformed through an electric generator, transmitted to motors, and transformed into mechanical work at the driven machines more efficiently than by a large number of small steam engines and steam pumps.

The adoption of the electric motor permitting the use of high-speed centrifugal pumps tends toward a smaller amount of power required for pumping. Energy is lost in a steam pump through external friction which is not recoverable, while the losses in a centrifugal pump go to heat the liquid pumped, which, in general, is desired. The continuous effort exerted by the electric motor permits the use of chain or gear drive in place of the less efficient belt connection usual with engine drive. The motor can be more closely connected to the driven machine, thus avoiding the losses involved in the use of the counter-shafting and long belts which are required by the steam engine.

The amount of steam required to produce the same amount of useful work is materially reduced, mainly by the generation of power from a large steam turbine instead of from a large number of small steam cylinders. The amount of steam required per horse power in a steam cylinder operating by throttle control, or non-expansively between the limits of pressure common in sugar mills, will range from 75 to 100 pounds, whereas the amount required by a steam turbine operating expansively between the same pressures will be half of the lower figure. This amount can be further reduced by higher steam pressures and superheat, to which the steam turbine is eminently suited but which is detrimental to the operation of the steam engine.

The large engines driving the crushing rolls and flywheel type vacuum pumps, when equipped with Corliss valve gear, can be made to approximate the performance of the steam turbine operating between these pressure limits. However, there are objections to the use of the steam cylinder because of the need for internal lubrication and the greater maintenance expense.

Radiation and leakage losses contribute largely to the extra fuel bill. A detailed study of a mill producing 179 tons of sugar per day disclosed the fact that electrification would remove 7500 square feet of high- and low-pressure piping serving steam pumps and engines. Conservative estimates of the radiation losses showed that the loss of heat from this cause alone accounted for $4,000 of the extra fuel bill or 20 per cent of the total amount.

The increased efficiency of heating and evaporating apparatus resulting from surfaces free from oil is a factor which, while varying widely with the individual mill equipment depending upon the measures taken to separate the oil from the exhaust, will effect a certain saving in fuel. With a given equipment and amount of juice handled, the exhaust steam pressure can be reduced thus decreasing the radiation losses and the heat lost in the condensate.

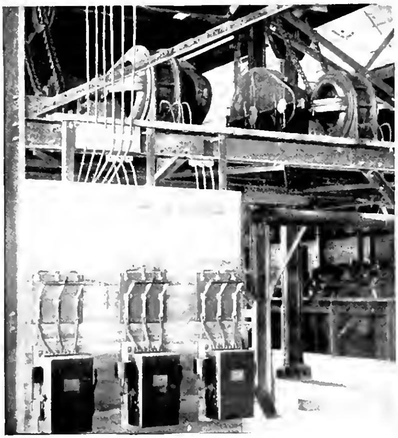
The reduction of the total amount of exhaust steam from the prime movers has a bearing on the practical operation of the mill. Even with the large loss from radiation and with remote engines and pumps exhausting into the air, there are times when exhaust steam will escape through the pressure relief valves. This is due to the temporary shutdown of some part of the plant using low-pressure steam, and results in a direct loss of heat which may have been generated from additional fuel.

Where the amount of exhaust steam from the steam pumps and engines is just equal to the normal low-pressure steam requirements, a reduction in the use of exhaust steam is sure to cause a loss of a greater amount to the atmosphere. Assuming the power-consuming units to continue under normal load, a decrease in the use of exhaust steam will raise the back pressure and will thus result in an increase of steam from the [illegible]. The [illegible] engines will [illegible] their normal speed, pump throttles must be further opened to pump the normal amounts of liquid, and hence the boiler pressure will drop increasing further the demands for steam. Whether the engine speeds are maintained or allowed to drop, thus decreasing the bagasse, extra fuel must be fed to the furnaces.

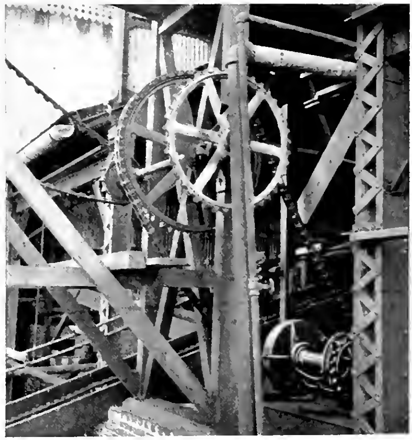
In an electrically driven mill, the exhaust steam from the turbines is less than that required for the low-pressure system. A certain amount of high-pressure steam must therefore be added through reducing valves in order to maintain the pressure in the low-pressure system. This high-pressure steam is superheated in passing through the reducing valve and re-evaporates some of the moisture in the low-pressure system. A reduction in the use of low-pressure steam will now cause a reduction in the amount of high-pressure steam through the reducing valve, and will effect an equal saving of heat without affecting the operation of the steam turbine or any of the power drives.

It is possible under these conditions to accumulate excess bagasse for use during a temporary shut-down of the milling plant or a reduction in the grinding rate occasioned by a shortage of cane. An excess of bagasse is desirable for use at the end of the crop, particularly when the bagasse is not accumulated with a sacrifice in mill efficiency.

The amount of extra fuel consumed in Cuban mills during the 1912-13 crop has been determined by the Government as amounting to 75 cents per ton of sugar produced. This season is chosen as representing the normal manufacturing period (preceding the world war) and as not being materially affected by the considerable number of old and new mills electrified since that date.



25-h.p. Back-geared Motors Driving Main Bagasse Conveyors, Central Delicias. The motors are mounted directly under the conveyor while the starters are on the operating floor below

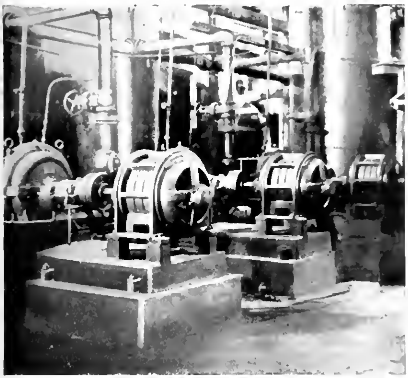


10-h.p. Back-geared Motor Driving an Excess Bagasse Conveyor. Central Santa Rosa

Labor

The labor item in a mill constitutes the greatest proportion of the manufacturing cost. In normal times it ranged from 4 to 10 per cent of the total cost of the sugar, depending upon the country. The former figure is the average for Hawaii and the latter for Cuba, with Porto Rico and Louisiana intermediate. The great increase in wages during the last few years makes the reduction of the manufacturing force very desirable.

The reduction in the number of attendants by electrification has been shown in a general way. In a steam-driven mill a detailed study was made of the number of operators and repair men which would be affected by a changeover to electric drive. After computing the wages chargeable to steam engine and pump attendance and determining the attendants known to be required with electric motor drive, it was found that the electrically driven plant would reduce the manufacturing and maintenance labor $38.61 per day. This mill was producing 1100 bags of sugar, 325 pounds each, per day. This would result in a reduction of 21.6 cents per ton of sugar. The force would be reduced by 26 men. This reduction would also effect a reduction in the clerical force in the general office. The men remaining in the mill would be better paid and have more congenial tasks, while the lower grade laborer removed would be made available for increasing the forces in the cane fields.



Three 50-h.p. Motors Driving 2-stage 450-gal.-per min Limed Juice Pumps. Central Mercedes

Supplies

The reduction of mill supplies effected by electrification is a very strong argument for the adoption of electric drive. Lubricating oil, and pump and engine piston packings are big items of expense. The electric motor and centrifugal pump, consisting of only revolving elements mounted in oil-ring type bearings, require a very small amount of oil. The pump packings surrounding the rotating shafts last a long time. The steam turbines and generators in the power house have similar oiling systems and likewise require very little oil.

In the steam-driven mill the lubricating oil runs from the bearings or is carried off by the exhaust steam and becomes a source of trouble, either by collecting on the centrifugal pump, or floor, or being carried into the steam-heating coils and calandria. In an electrically driven mill, however, the oil returns to the oil wells of the pump and motor bearings and is again carried up on the shafts, thus being used over and over again. No oil is used inside the turbines, so that the exhaust steam is entirely free from oil.

The oil, grease, packing, waste, press coverings, soda, re-agents, and replacement of worn-out parts in a steam driven mill average 56 cents per ton of sugar. Of this amount a saving of 19 cents per ton is effected by electric drive.

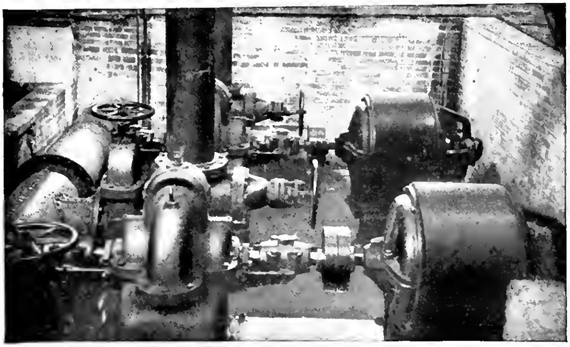
Two Motor-driven Scum Pumps, Central Australia. The starters mounted on the column have overload relays adjusted to shut the motors down when the pressure on the filter presses reaches a given value

Repairs

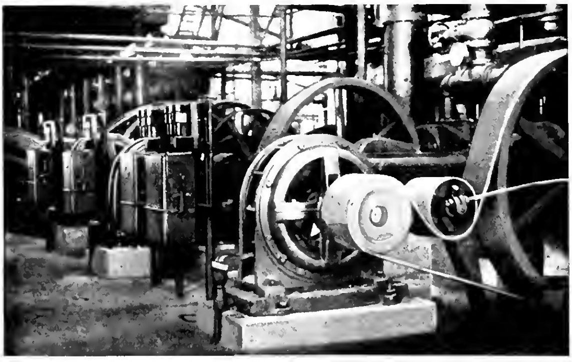
The elimination of reciprocating steam pumps and engines and the substitution of centrifugal pumps and electric motors reduce the wear and breakage of parts to a negligible amount. Steam and pump cylinders require frequent renewal of packing rings, and crank bearings must be often tightened. The packing rings in centrifugal pumps are longlived and the bearings of the pumps and motors, being well lubricated, run indefinitely without adjustment.

It is common practice in steam-driven mills to dismantle pumps and engines at the end of each crop and slush the wearing surfaces with a rust preventive. Parts requiring repairs are then attended to during the dead season; and before the beginning of the crop all machinery is cleaned, adjustments made on all bearings, and the machines are assembled.

An electrified mill requires a very small amount of labor to prepare it for the dead season and for the beginning of the crop. The motors need only be covered over to protect them from dripping water. The centrifugal pumps may readily be opened up to clean out the juice or syrup. In starting up the mill there is practically nothing to be done but to uncover the motors, drain and refill the bearings, and repack the centrifugal pump shafts.



Two 100-h.p., 1200-r.p.m. Motors Driving 4500-gal.-per-min. Injection Water Pumps. Central Santa Rosa



Four 75 h.p., 720-r.p m. Motors Driving 1900 Cu. Ft. per Min. Vacuum Pumps and 464 Cu. Ft. per Min. Air Compressors. Central Mercedes
The idler pulleys permit short belts to be used

Another important item is the cleaning of steam heating coils. The oil deposited on the inside surface of heating coils by the exhaust steam of engines and pumps must be occasionally removed. The presence of a small film of oil materially reduces the heating and evaporating capacity of heaters, evaporators, and vacuum pans. The cleaning operation is expensive, because of the material required and of the necessity in some cases for scraping the surfaces. The exhaust steam in an electrified mill being absolutely free of oil saves this item of cleaning expense.

The foregoing items of repair expense are incurred mostly in the dead season, the slight repairs necessary during the crop being charged to the maintenance account. The Government reports $1.71 per ton of sugar for machinery and building repairs. Electric drive can be shown to reduce this amount by $.09.

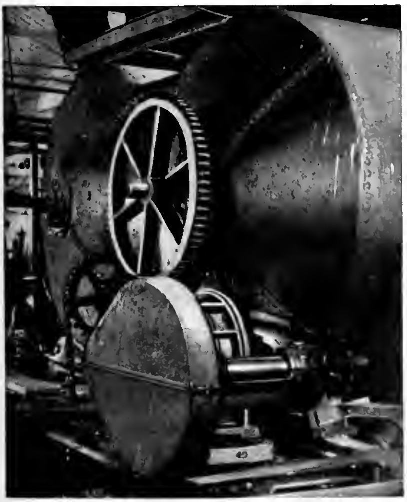
Production

In an existing mill the output is limited by the available cane, by the grinding capacity of the rolls, by the capacity and arrangement of the heaters, evaporators, pans and tanks, or by the continuity of operation of the machinery and apparatus. Electric drive will increase the output of sugar which in a steam-driven mill may be limited by any of the foregoing conditions.

An increased yield from a given amount of cane is possible through the use of an abundance of maceration water. The steam economy in an electrically driven mill permits the evaporation of the maceration water without the consumption of extra fuel. Maceration has been credited with an increased yield as high as 15 per cent above that before its use, but it is doubtful if the total gain observed was due wholly to the maceration water added. When a mill is electrified the evaporating apparatus is usually altered and the efficiency of the rolls is also increased, both of which contribute to the increased yield.

The use of maceration water is now employed quite universally as it is found that even the additional fuel required in a steam-driven mill renders a greater return in the value of the increased yield of sugar. Molasses is used where its value as such is less than the cost of the corresponding fuel value of coal, wood, or oil. The amount of water used is undoubtedly less than the economic limit that could be used to produce the maximum profit.

With the conservation of bagasse resulting from electrification, a greater amount of water will be used with a corresponding gain; but even under these conditions there is still an



35-h.p., 600-r.p.m. Back-geared Motor Driving Open Crystallizers, 1150 Cu. Ft. Each, a Magma Conveyor and First and Second Magma Pumps. Central Santa Rosa. The motor is mounted out of the way on a platform of the closed crystallizers shown

economic limit if extra fuel is required for the pumping or transportation that could be replaced by electric power generated from the bagasse.

The saving in fuel by electrification has previously been considered with maceration as usually practised in steam-driven mills. An increase in the amount of water may be conservatively assumed to increase the yield 5 per cent additional. With sugar costing $40.00 per ton at the mill, the increased yield will have the effect of reducing the

15-h.p., 600-r.p.m. Motors Geared to Triplex Plunger Molasses Pumps. Central Mercedes

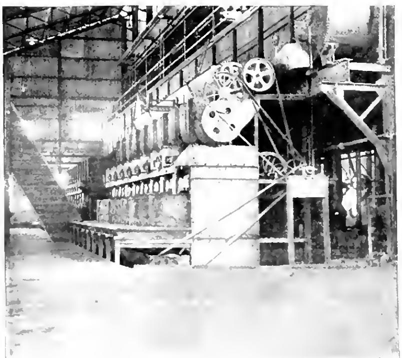
cost of production by a like amount or $2.00 per ton.

The yield can be increased by electrification for other reasons than increased maceration. With a proper electric drive applied to the rolls, higher extraction is obtained due to the ability to control the relative speed from roll to roll and to adjust the grinding rate to accommodate the varying supply of cane. The meters on the motors driving the individual sets of rolls give a continuous indication of their operation and each set of rolls can be adjusted to operate at maximum effectiveness.

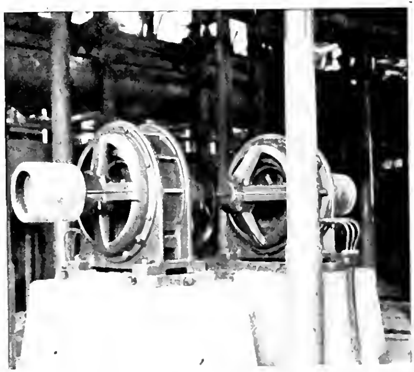
The capacity of the heaters, evaporators, and pans is increased because of the clean steam heating surfaces due to the absence of oil in the exhaust steam. The capacity is also increased as the vessels do not have to be taken out of service to have the oil film cleaned off.

Continuity of service in a sugar mill is of utmost importance. It is customary to operate the mill to the utmost capacity during the harvesting of the crop. Any shut-down period reduces the amount of cane ground and, as the labor expense and fixed charges [illegible], the cost of manufacture is thereby increased. Electric drive has won the recognition of being the most reliable [illegible]. There are many cases of continuous operation of electric motors for periods of several years without a shut-down due to the electric system. It is customary in an electrified mill to install spare pumps with motors where the continuous operation is essential and spare motors for replacing any motors on power drives. The relatively low cost of the electric motor and centrifugal pump and the ease of substitution of one motor in the place of another make possible the stocking of spare units without objectionable expense.

Twelve Induction Motor Direct Driven 40 In. by 24 In. Centrifugals. Central Violeta, Cuba. Some of the control panels are shown mounted between the motors. The master control switch is combined with the brake lever



Eight 40 in. and ten 36-in. Centrifugals, each Bank Driven by a 75-h.p., 720 r.p.m. Motor. Each motor also drives the mixers, conveyors, and sugar elevators with each bank. Central Australia



Two 75-h.p., 720-r.p.m. Motors Driving Centrifugals shown adjacent. Central Australia

The majority of interruptions in a cane sugar mill are due to slipping of the rolls and to repairs necessary for the steam engines and steam pumps. Engines frequently stop on dead center and time is consumed in getting started after adjustments have been made. The shut-down periods of mills due to slipping can be practically eliminated by electric motor drive through the indications of the power meters of the individual motors. By a re-adjustment of the relative speeds of adjacent sets of rolls, the rolls can be made to take their proper division of the load and slipping can thus be prevented.

Assuming that the rolls are shut down for ten minutes daily, due to slipping or for repairs to the engines or pumps, it will be found that the time lost will amount to an increased cost of 3.7 cents per ton of sugar. This figure is calculated on the basis of the average manufacturing cost per ton of sugar after deducting the cost of cane and sugar containers, as it is considered that these items of expense are not incurred with a reduction in the amount of cane ground. With the mills shut down and with extra fuel already consumed, still more fuel will be required, and it is found that the cost of the additional fuel will equal the labor expense.

Centrifugals

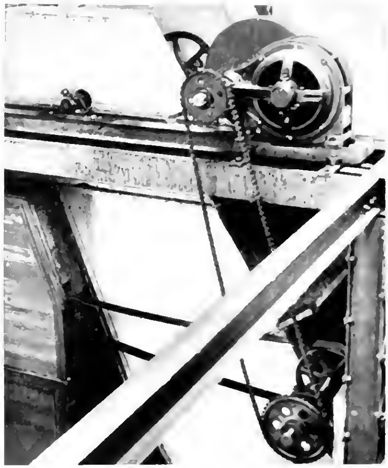
The group drive of centrifugals by the electric motor contributes to the general benefits resulting from electric drive. The adoption of direct coupled motors to the individual machines effects further marked economies.

A special motor has been designed for this application. The motor is of the vertical semi-enclosed type and has a base suitable for connection to the centrifugal base. The motor shaft drives the centrifugal shaft direct through a flexible coupling. No belts or clutches are employed. The motor control switch is combined with the brake lever so that all operations are controlled through one handle. The motor has a phase-wound rotor with external resistance. This permits the use of an additional resistance to give slow speed for a mechanical discharger. The motor is designed to operate on a 2½-minute cycle. This increases the output per machine and operator considerably on final sugar above that possible with other types of drive. A smaller number of units and operators is thus required.

Another type of direct motor drive has been very popular. The method of connection is similar excepting that a centrifugal clutch is interposed between the motor and centrifugal. The motor jumps up to speed very quickly and the clutch pulls the centrifugal after it. The wear of the clutch shoes is rapid when adjusted to give quick acceleration and low speed operation for mechanical discharging is not feasible.

The direct coupled drive requires 10 per cent less power than the belted group drive and 20 to 30 per cent less than the water drive. The drop in voltage experienced in some installations when the centrifugals are started up can be overcome by the use of a voltage regulator.

The absence of belts and clutches removes the greatest sources of trouble found with centrifugal drive. The maintenance expense is thereby practically eliminated. The initial cost is greater per machine than with group drive; but considering the smaller number of centrifugals required, lower cost of operation, labor, and maintenance, it will be found



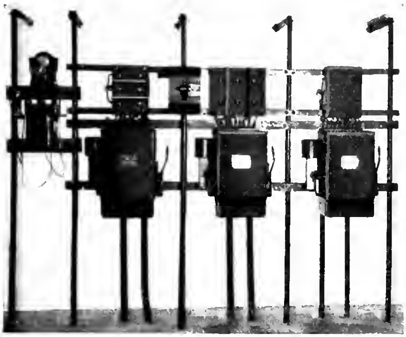
15 h.p., 900-r.p.m. Back geared Induction Motor Driving Two Sugar Elevators and Conveyors Central Delicias

that direct drive will prove cheaper even for the first year of operation.

Water Supply and Repair Shops

A supply of pure fresh water is required at all mills. This water is usually obtained from a nearby stream or well and must be pumped to the mill. The distance makes it necessary for a steam driven mill to provide a boiler plant with the necessary attendant. The small size power plant and the constant service of an attendant bring the unit cost of water delivered at the mill to a high figure.

The unit cost of water at an electrically driven mill [illegible] mill. [illegible] generated from the bagasse at the high efficiency of the large turbine-driven generator. Even the services of a regular attendant at the pumping station can be dispensed with. The pump can be started and stopped by suitable control equipment located at the mill. Such an equipment is shown below. An ammeter at the mill will indicate the proper operation of the pump. Automatic starters can be furnished to start and stop the pumps and maintain the level of the water in a storage tank within prescribed limits. In this manner a supply of water is always at hand while the pumping outfit runs only for the time required to maintain the supply.

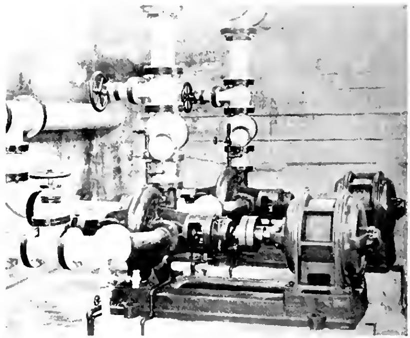


Compensators in the Power House for Controlling Pumps at a Distance. Central Santa Rosa. One compensator controls a pump motor at the station, another at a dam two miles distant

The amount of water and distance from the mill will vary widely for different mills and it is difficult to make an assumption that will be representative, but it may be assumed for a steam-driven mill that the fuel expense will amount to $1,000 per year, and constant attendance is required. The wages of two men per day, each working half a day, will amount to $3.50 or $1278 per year. The total yearly expense for fuel and labor amounting to $2,278 can nearly all be saved by electric drive. The fuel is furnished by the bagasse during the grinding period while extra fuel is required during the dead season. Since the power for the dead season is generated in an efficient central plant by a small auxiliary power unit, the amount of fuel chargeable to the pumping plant is small and may be considered as being balanced by other items of expense in a steam-driven plant which do not appear in one electrically driven. On the basis of 15,900 tons of sugar per year, the cost will be reduced by 14.3 cents per ton.

The electric drive of repair shops is attended with similar economies. While machine shops are commonly located in the mill building, carpenter shops are usually in a separate building and have their own boiler plants. The saving in fuel and labor is difficult of determination as they are run so irregularly.

The fuel consumed by the machine shop will be less with electric than with steam drive due to the higher efficiency of the larger power unit in the main power house. It may be assumed that the carpenter shop operates from waste wood but a fireman is necessary for the boiler.



35-h.p. Induction Motors Driving Supply Water Pumps in the Pump House at Central Chaparra

The electric drive is particularly of advantage in repair shops where the operating periods are irregular. The tools can be started up at any time without waiting for steam or for an engine to warm up. Where the tools are individually motor driven, power and hence fuel are consumed only while they are in operation.

Tools can be located at the point most convenient for their use, such as the car shop, engine house, and mill. An example of the last is shown opposite. A motor with a back gear reduction was connected to a roll, and the roll trued or grooved without removing it from its bearings.

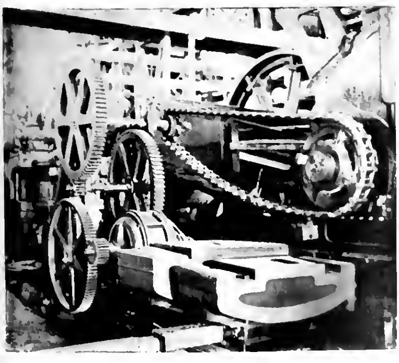
Illumination.

A survey of the lighting of cane sugar mills leads to the conclusion that in many cases considerable economic advantage can be secured by the proper application of Mazda lamps with modern reflector equipment. The lighting circuits can be connected to the mill power system.

Proper illumination is probably the most effective single agent in accident prevention. Statistics show that a large percentage of accidents results from falls. Good illumination readily permits a workman to avoid obstructions and dangerous conditions. Dangerous positions in mills should be well lighted. This is particularly true around the cane unloading shed, grinding rolls, defecators and filter presses; all of which present dangers to workmen which can be minimized by proper illumination. Light is also a preventive of accidental or malicious injury to machinery and apparatus.

50-h.p. Motor Driving a Rip Saw and a 25 h.p. Motor Driving a Planer and Woodworking Tools in the Carpenter Shop. Central Delicias

Good lighting facilitates quick and sure movements on the part of workmen, thus increasing their output and reducing losses. It further promotes supervision, and thus is a deterrent to idleness. The cheerful atmosphere of a well-lighted mill is an incentive to greater activity. In a cotton mill district, the relighting of one of the mills drew employees away from adjacent mills to such an extent that the latter were required to provide better lighting in order to retain their working force.



15-h.p. Back-geared Induction Motor Driving a Cane Crushing Roll for Turning Off the Surface Central Mercedes

The cost of good lighting, figured as a lump sum, sometimes seems large but compared with the payroll it is very small; so that an average increase of one or two per cent in the accomplishment of employees will usually more than repay the entire lighting cost.

In the manufacture of food products, cleanliness is always important. Dark corners and poorly lighted spaces furnish opportunity for untidiness and dirt collection. In all processes connected with the manufacture of sugar, it is essential that adequate illumination be provided to promote extreme cleanliness that the yield and quality of the sugar may be high.

The Mazda lamp is now the universal electric illuminant for interiors, because of its adaptability, convenience, and high economy. The same lamp meets the requirements of the office, the mill, and the yard, the only difference is in the size of the units, reflectors, and arrangement.

Mazda 110-volt lamps range in size from [illegible] to 1000 watts, and give from two to four times as much light as the old carbon lamps, and usually over double the light of the [illegible]

The scientifically designed reflectors for each size of lamp meet all requirements. Porcelain enamel direct lighting steel reflectors meet the requirements in the manufacturing department, while for the offices and living-rooms either direct or semi-indirect opalescent glass reflectors are used.

A scheme of general illumination for the mill is usually preferable where conditions will permit. This system consists of utilizing medium or large size lamps with proper reflectors, symmetrically spaced, thereby producing approximately even illumination over the entire floor area. Where it is desirable to illuminate particular areas more brightly, lighting units should be located with respect to the work, utilizing the small or medium sized lamps so as to secure proper distribution and direction of light.

The adequate lighting of the yards is quite essential, both to facilitate night work and as a matter of protection. Fixtures such as those used for ordinary street lighting meet these requirements. The series lighting system is the most economical and is well suited for extensive lighting although the multiple system gives good results for a small amount of lighting near the mill. Flood-lighting projectors also give very satisfactory results where it is desirable to light a portion of the yard located at a considerable distance from the source of supply. For such service as patrol work, loading and unloading cars, boats and carts, very effective illumination may be obtained by the use of these lighting units.

In the grading of raw and refined sugar, it is necessary to match the color with standards under daylight conditions. Artificial illuminants simulating daylight in color value are available to meet these requirements.

Where the greatest accuracy is necessary, color matching lights should be used; e.g., the Moore light which produces light by electric discharge in a glass tube filled with carbon dioxide gas or the Trutint color-matching unit which utilizes the regular Mazda C lamp contained in a reflector housing, beneath which is supported a color-correcting glass plate. Both of these units produce light approximating north sky light. In processes where extreme accuracy is not essential, Mazda C-2 (special blue bulb) lamps will be found to give good results.

Electric Traction

The reduction in fuel required for the mill proper and the use of this fuel for power outside the mill has been mentioned. Electric traction offers an attractive means of utilizing the excess power with great benefits. The extent to which railroad electrification will pay depends upon the amount of power available, the length of the lines, the grades, and the train schedules.

The steam locomotive is wasteful of fuel. The heat in the exhaust steam lost into the atmosphere could be put to good use in the mill. The fuel burned while the locomotive is idle entails further waste. The majority of cane fires originate from sparks of passing locomotives.

The electric locomotive is highly efficient and where excess bagasse is available the extra fuel is saved. Power is consumed only while running. As there is no fire on the electric locomotive, the number of cane fires is greatly reduced.

It will pay to employ electric traction, at least adjacent to the mill. For placing cane cars on unloading platforms electrically driven winches are well adapted. The winch, page 267, is suitable for installation outdoors on a foundation. The electric motor inside is started or stopped by a pedal, thus leaving the operator's hand free to handle the rope on the winding drum.

The switching around the yard can be accomplished by a small trolley type locomotive.

The 60-ton trolley type locomotive shown on page 267 is suited for hauling cane trains from the cane fields and loading stations to the mill.

The direct-current power required by the trolley system can be derived from the alternating-current mill circuit by means of of a synchronous converter equipment. This direct-current power can then be readily utilized for driving the cane loading hoists.

Electrical Equipment

The applications of electrical apparatus in cane sugar mills are shown in the various illustrations and their adaptability is described from different economical points of view. The electrical apparatus consisting of turbine driven generators, switchboards, motors, control apparatus, and wiring should be of the simplest form and strongest construction possible, consistent with the service. This is desirable in any installation, but the unusual operating conditions in cane sugar mills require somewhat special equipment.

The mill is usually operated during the dry season and the apparatus therefore lies idle during that part of the year when there is the maximum amount of moisture in the air. During the operating period, motors and control apparatus are subject to occasional splashes of water and juice, and may at times be enveloped in a cloud of steam. The motors and control, therefore, have moisture-resisting insulation.

Three-phase, 440-volt, 60-cycle alternating current has been generally adopted as an economical, safe, and reliable form of electric power distribution. This permits the use of the simple induction motor, of which the squirrel cage type is found to be suitable for 90 per cent of the power drives.

60-ton Trolley Type Electric Locomotive for Bringing in Cane Trains from the Fields

Simplicity in design and mechanical strength are essential for the continuous operation in a cane sugar mill. The machinery must operate without interruption at least from week to week, for a period averaging 136 days. The attendants are usually unskilled in operating machinery and the electrical apparatus must be equipped with safety devices to protect both the machinery and the operator.

Motor-driven Winch for Placing Cane Cars on Unloading Platforms

All electrical terminals and contacts in a mill should be insulated or enclosed to prevent shocks. The wiring for connecting to motors and control apparatus should preferably be run in underground metal conduits. The motors and control apparatus should be equipped with conduit terminal connections to effectively cover the terminal connectors.

It is sometimes expensive to open up a concrete floor and install conduits in an existing mill, in which case the main feeders of single conductor cable can be run horizontally overhead on insulators to the centers of distribution, and then vertically by triple-conductor cables through metal conduit mounted on pillars adjacent to the motors or control. An example of this method is shown on page 268.

Because of [illegible] of the cables and the connections to lamps located overhead, the lighting system is best installed in conduit overhead. Junction [illegible] boxes facilitate this method [illegible]. The lamp receptacle and [illegible] holder can be fastened direct to the boxes and thus there are no exposed wires. Panel boards [illegible]

Total Economy

In stating the benefits of electric drive an attempt has been made to place a money value on the savings. This has been possible of quite accurate determination in the case of fuel, labor, supplies, and repairs; but for increased yield, shutdowns, and pumping of supply water certain assumptions have been made. For other items, such as repair shops, transportation, administration, and welfare work the local conditions vary so widely that it is not feasible to evaluate the expenses or savings. These must be determined from a study of the individual mill.

Open Wiring in an Existing Mill
Horizontal lines are carried on insulators and anchored by turn-buckles. Vertical connections are made through iron conduit to the control apparatus

The savings from the definitely determined items are so great that the decision to electrify can be made upon these alone. Moreover, these figures have been taken from data collected on a conservative and impartial basis. Details have been given as far as possible, so that a mill owner can compute the figures applying to his own mill. Table I summarizes the various items on a basis of the average Cuban mill, producing 102 tons of sugar per day or a total of 15,900 tons in a crop of 156 days. The aggregate savings are considerable and will pay for the cost of changing over an existing mill in a very short time. If only the interest on the added investment is considered, the net saving per year increases the net profits by a large amount. The market value of a mill is increased by a greater amount than the cost of the improvements.

TABLE I

	Steam	Electric	Saving
Fuel.	$11,925.00	. .	$11,925.00
Labor (Mfg.). . .	42,930.00	39,500.00	3,430.00
Supplies.	8,900.00	5,880.00	3,020.00
Repairs.	27,190.00	25,760.00	1,430.00
Shut-downs (Labor).	590.00	. .	590.00
Water supply and miscellaneous . . .	2,278.00	. .	2,278.00
			$22,673.00
Increased yield, (maceration). . . .			31,800.00
Total reduction per year			$54,473.00
Reduced cost per ton of sugar. .			$3.426

Oriental Hospitality to Americans

It is a pleasure to know that our relations with the Orient are not limited merely to dollar and cents trade, but embody mutual respect, confidence, and friendliness. This fact has been exemplified recently by the hospitality extended to and the honors conferred upon American business men while in Japan and China.

We reproduce some addresses, editorials, and articles clipped from those enterprising Japanese and Chinese magazines and newspapers which contain sections printed in our language. These clippings should be of particular interest to the electrical fraternity, as they refer to the recent trips to the Orient by Mr. E. W. Rice, Jr., President of The American Institute of Electrical Engineers, and by Mr. Gerard Swope, Vice-President and General Sales Manager of The Western Electric Company.

An agreeable reminder of American history is contained in the Japanese editorial reference to the work of Commodore Perry in promoting adequate trade agreements with Japan. This important event is recognized on both sides of the Pacific Ocean as the beginning of the international camaraderie now firmly established between the Old and the New World.—Editor.

(Magazine Article)

ADVANCE WELCOME TO MR. E. W. RICE, JR.

From the far country across the Pacific, Mr. Rice, the President of the General Electric Company, has come. With what feeling has his visit to our country been expected by the electrical circles in Tokyo, since it was first announced here some time ago! It is almost impossible for us to give free vent to our heartfelt joy now that we have received such a great guest amidst ourselves.

He represents the greatest organization of its kind in the world, and we owe to his company so many thanks for the most part of the present development of electrical engineering in Japan, which was only made possible by the good will and invaluable assistance of the company.

When we hold a welcome meeting in honor of Mr. Rice tonight, we can not but indulge in the recollections of those days when young Japan had to struggle for her life on the brink of a fatal precipice and when the nation whom Commodore Perry awoke from a deep slumber, began to thrust aside the veil of ignorance and isolation to see the wide civilized world with its achievements and possibilities of all kinds. From those early days of her maturity Japan has been indebted to the United States of America for her unparalleled friendship and good will, and today the two powers are cordially united and have promised faithfully to continue the good relation between themselves which the unprecedented event of the present year has made far more perfect and intimate than ever.

Decoration of Third Order of Rising Sun

Orders of the Rising Sun were conferred upon E. W. Rice, Jr., and Gerard Swope by the Emperor of Japan.

May our esteemed guest enjoy a fine time of it during his sojourn on this side of the ocean, and see with his own eyes how grateful not only the people but also the country itself feels toward the nation to whom it owes the most part of its development, and may the nations who have become close friends, especially in the field of electrical engineering, remain for ever faithful to each other for the sake of human progress and universal brotherhood.

DENKI SEKAISHA

(Copied from *Ohm*, January 1918)

(Editorial)

MR. E. W. RICE

Mr. E. W. Rice, Jr., the President of the General Electric Co., who was decorated with the third order of the rising sun from H. M. the Japanese Emperor, was entertained at the Seiyoken Hotel, Tsukiji, on the 23rd Nov., 1917, by the members of the Electrical Society, Japan, joined with the Illuminating Engineers' Society, Japan.

The room was profusely decorated with crimson leaves of the native maple, miniature

Luncheon at Osaka by Illuminating Engineering Society of Japan

Electrical Officials and Guests after Luncheon at Osaka, Japan electric lanterns painted with Japanese and American flags hanging among the leaves.

About 150 eminent engineers attended the meeting, most of whom once visited Schenectady.

After the dinner, a cinema picture was shown, which Mr. Rice brought with him. Mr. Rice's explanation of the cinema as well as his speech on the dinner table, together with Prof. Yamakawa's speech, representing the Illuminating Engineers' Society, are given on the following pages.

ADDRESS BY DR. G. YAMAKAWA

President of the Illuminating Engineering Society

"It is my great pleasure and honor to say a few words in this meeting on behalf of the Illuminating Engineering Society of Japan, of which I am the President. This dinner has been arranged by the members of the Japanese Institute of Electrical Engineers and the Illuminating Engineering Society of Japan and others who are connected directly or indirectly with both of these institutions, to welcome Mr. E. W. Rice, the President of the American Institute of Electrical Engineers and the President of the General Electric Company in America, who has been so kind to visit us on occasion of his pleasure trip to the Far East.

"Everybody knows that modern civilization is only a ripe fruit of the progress of science and its application to all phases of human life worked out by eminent scientists and engineers. We, electrical and illuminating engineers, take great pride in the important part which we play both in scientific researches and practical applications in the range of the electrical and illuminating engineerings to the embellishment of our life in this world of science and industry.

"No one can but recognize the admirable achievements and contributions of the American Electrical Engineers, who are represented by our great guest here tonight, since it was they who brought about so many great inventions and discoveries in this line of science and industry. Especially, the branch of the Illuminating Engineering science which is now established as an independent science, owes its present stage of marvelous development mostly to their energy and efforts. Moreover, the American Society of Illuminating Engineers is the first of its kind in the world, to be followed by the societies in England and other countries.

"Besides the well-known inventions of epoch-making illuminants which revolutionized the lighting industry and afford invaluable advantages to human life as Gem lamps, mercury vapor lamps, Mazda lamp, and gas-filled lamps, the progress of the economical and scientific methods of their applications including the latest invention of the floor lighting system, have developed the field of the lighting industry to such an extent, that it may not be long before we can see the realization of Mr. Edison's dream of changing night to day.

"And all these things, among many other valuable contributions, have been accomplished mostly by the Institution of Electrical Engineers and Manufacturers, represented here tonight by our distinguished guest.

"Now, it is a fact known all over the world that new Japan owes its civilization to America, and the progress of science and industry in this country, so far as electricity is concerned, up to the height of the present stage of development would have been impossible without friendly guidance and kind co-operation of the American people, who have spared no pains in educating our youth, training our engineers, and opening the doors of their factories to our visitors.

"Our Illuminating Engineering Society is yet young, being started only a year ago. There is yet a big field in this line of science awaiting for cultivation, and it will be a long time before we can leave the present stage of illuminants behind ourselves to reach the goal of the so-called cold light, as it is dreamed now. But our illuminating engineering science should also throw its stones, few as they may be, to the pile of progress of this science for the sake of the prosperity and happiness of mankind, and it is our earnest desire we wish to be connected to our American friends through the kind [illegible] of our distinguished guest that we should like to ask them to aid [illegible] forward just as before.

"We wish [illegible] American Institution [illegible] and future [illegible] unity [illegible] appreciation [illegible] [illegible] science.

"Gentlemen [illegible] American Institute [illegible]

IMPRESSIONS OF JAPAN

Speech Delivered by Mr. E. W. Rice, Jr., at a Dinner Given in His Honor at the Tsukiji, Seiyoken Hotel, on November 23rd, by the Japanese Institute of Electrical Engineers and the Illuminating Engineering Society.

"To the Members of the Japanese Institute of Electrical Engineers and of the Illuminating Engineering Society and friends who are assembled here this evening to extend to me this great honor, I wish to express my sincere thanks. I would not be human if I were not tremendously impressed by the friendship and hospitality shown here tonight and by the beautiful decorations so unique and so characteristically Japanese.

"I have never in all my travels seen such a beautiful country; there are, of course, beautiful things and beautiful scenery in America and in other portions of the world but I have never seen such continuously beautiful scenery as in your country. Environment has a powerful influence on the people of a country and we therefore may expect that people who live in such a country should be wonderfully virile, versatile, and artistic, which I firmly believe you are.

"I have been greatly impressed by the wonderful industry of every one in this country, everybody seems to be doing something and to be busy. The next thing that impressed me was your constant cheerfulness; as we say in America you seem to have a smile "that won't come off." Well, now, I have been told by your critics that this characteristic smile of yours is due to your government which orders you to smile. I cannot believe that there is any organization so great or Government existing that can make sixty millions of people all smile all the time —it must be due to a natural and sunny disposition.

"You have all been kind enough to speak in the most complimentary way of the accomplishment—industrial undertakings—which I have the honor to represent and the the assistance which our organization has rendered to Japan. I can only say that we are glad, very glad, if we have been able to help you.

"We are proud of the G-E Japanese boys; they have "made good" as far as I can see wherever they are in this country. I understand that many of the gentlemen I have the pleasure of addressing now have worked in the G-E Factories in America and that makes me feel as if I were at home amongst my friends. We are glad to have had you there, and we shall be glad to have more of you come to us.

"Dr. Saitaro Oi, President of the Electrical Society of Japan and Dr. Gitaro Yamakawa, President of the Illuminating Engineering Society, have spoken of my position as President of the American Institute of Electrical Engineers. The position is one of great honor—I am deeply conscious of my great responsibility in representing such an institution, whose past Presidents have included such peers in Electrical Science as Alexander Graham Bell, inventor of the telephone, Elihu Thomson, inventor of the electric welding and systems of electric lighting, Sprague, pioneer of the electric street car and others equally distinguished—a Society which also included amongst its members such men as Edison, Carty, Scott, Lamme, Weston, Steinmetz, Whitney and Coolidge. It gives me most intense pleasure to bring to you here in Japan a message of goodwill, congratulations, and best wishes for future work and co-operation from our great organization. The American Institute of Electrical Engineers, in which message I know that every one of our members, including those illustrious ones which I have mentioned, would heartily join if they were present.

"While today we in America and you in Japan are companions in arms, fighting a righteous war for the preservation of all the ideals that we both consider essential to the preservation of a human and happy civilization, yet we engineers and scientists are naturally men of peace, devoted to ideals of co-operation and helpfulness, not to strife. We are truly international in spirit. We use the same scientific methods, symbols —the American ampere is the same as the Japanese ampere—the volt, the watt, the Henry, the Kelvin are the same in England, in France, in America and Japan, and even in darkest Germany.

"I like to believe that eventually through science and its beneficial works, the real brotherhood of man will eventually become firmly established; that mankind everywhere will come to believe that co-operation is better than competition, that a spirit of tolerance, of appreciation of each other's good qualities and patience with each other's shortcomings will take the place of depreciation and prejudice, founded largely on ignorance.

"I firmly believe that the future welfare of the world lies largely in our success in bringing about universal scientific education, which will dispel ignorance, the twin brother of prejudice, will remove the principal forces which make for misunderstanding and for war."

(Abstracted from the *Denkisekai*, Dec. 15, 1917)

THE KING OF THE RAILS

Address of Mr. E. W. Rice, Jr., accompanied by Cinema of the same title

"If in my remarks and illustrations tonight I seem to limit myself to General Electric apparatus, I beg of you to believe that I am not unmindful or unappreciative of the magnificient work done by other engineers and manufacturers. My excuse is that I am naturally more familiar with the G-E apparatus. Besides, in my hurried visit to this country, my time is so occupied that it would be impossible for me to prepare anything original, or dealing with matters which would require very special preparation. I wish to particularly acknowledge my indebtedness to Mr. B. H. Morash, who is largely responsible for the material which I have employed.

"It is my impression that Japan not only needs more railways but that even now or certainly in the near future, her existing railways will be entirely inadequate to take care of the traffic which will exist. One of the great economic advantages which electrification of steam railways has to offer, is a very substantial increase of capacity to handle traffic, over the same existing tracks and grades. It is not too much to claim that electrification of a single track railroad, especially over mountain grades, will practically double its capacity, or be equivalent to double tracking the road. The first cost of such an enterprise will be also much less in normal times than the cost of double tracking.

"Another great advantage of electrification follows from the ability to thereby utilize water power, with manifold advantages to the country in the saving of coal and the development of other collateral industries. It seems to me that you would, therefore, be interested in a brief description of a notable instance of electrification of a steam railroad in America which involves the use of water power, and which is otherwise notable for its size, engineering feature, and great success. I hope also to add something to the interest of the occasion by showing you by a "movie" show the interesting feature of this great enterprise.

"The demands upon the steam railroads in America are becoming more severe every year with the growth of both passenger and freight traffic. The steam locomotive has reached a high state of development but its best performance fails to meet the requirements in many instances. Railway executives are seeking means to increase the freight tonnage of the present tracks, and to effect economies of operation. Rates are controlled by various governmental bodies, and with labor, fuel, and supplies continually mounting in cost, some solution to offset these adverse factors must be found, if capital is to be secured for the extensions which are absolutely necessary. If a substitute type of motive power is to be employed, it must not only be more reliable and economical and offer greater hauling power than the best steam locomotive, but the net result of a company's earnings must justify the investment. The most thorough and painstaking investigators concede that electrification offers an admirable solution in most instances."

(The Japan Advertiser, Tokyo, November 24, 1917)

SEES WORLD PEACE THROUGH SCIENCE

Mr. E. W. Rice, Jr., Speaks at Banquet Given Him by Japanese Electrical Leaders

Expressing the hope that through science and its beneficial works the real brotherhood of man will eventually become firmly established, Mr. E. W. Rice, Jr., president of the General Electric Company, Schenectady, N. Y., spoke at the banquet tendered him last night by the Japanese Institute of Electrical Engineers and the Illuminating Engineering Society of Japan. Mr. Rice's position as the guest of these bodies bore all the more importance from the fact that he was recently elected president of the American Institute of Electrical Engineers.

Two hundred and fifty guests attended the banquet, which was held at the Seiyoken Hotel, Tsukiji. Japanese prominent in the electrical field of this country were present, including Dr. Oi, president of the Japanese Institute of Electrical Engineers, who welcomed Mr. Rice in a short speech. He stated that the Japanese electrical society, established thirty years ago, now had a membership of over 3,000.

Japan's Industry Impressive

Mr. Rice, at the beginning of his speech, said he had been impressed by the wonderful organization of industry in Japan, every-

At the Factory of the Osaka Lamp Company. Note the Japanese Electric Sign

Peking Electric Light Company Officers and Guests, Peking, China

Right to left, Front row—1, Tsang Shi Sing; 2, Mr. Hart; 3, Sze Lai Chuen; 4, E. W. Rice; 5, V. Meyer; 6, Yen Kung Chu[illegible] 7, W. F. Carey; 8, Kwan Kwung Lun. Second row—1, Fung Su; 2, Kiang Tien To; 3, Mr. Hu[illegible]; [illegible] Chow Kia Yi; 5, Tseng Tsuen Yi; 6, Sue Chun Siao; 7, Ho Ue Cheng; 8, Suen Toh Yu. Third row[illegible]1, W. A. Mitchell; 2, Q. T. Chen; 3, R. Rankin; 4 Au Tung.

body was doing something—and he had also been forcibly struck by the cheerfulness that seemed to prevail everywhere.

The guests included Dr. Count *Shiba*, *Y. Yamakawa*, vice-president of the Japanese Institute of Electrical Engineers; Prof. *Kamo*, Dr. *Kishi*, Prof. *Nagaoka*, Dr. *Tagawa*, *K. Iwatdare*, *T. Matsumoto*, president of the Fujikura Wire Co., Dr. *S. Kimura*, *Y. Shinjo*, *J. R. Geary* and others representing all fields of the electrical industry in Japan.

Mr. Rice, who has been extensively entertained in Tokyo, will return to America on the "Shinyo Maru" December 3.

(Abstracted from the Japan *Advertiser*, Tokyo, Sunday, Dec. 2, 1917)

EMPEROR HONORED TWO LEADERS IN AMERICAN ELECTRICAL WORLD

Mr. E. W. Rice, Jr., and Gerard Swope Have Promoted Industry at Home and Co-operation with Japan

When His Majesty the Emperor of Japan conferred decorations upon Mr. E. W. Rice, Jr., president of the General Electric Company, and Mr. Gerard Swope, Vice-President of the Western Electric Company, he honored two men whose achievements have marked them as leaders in the electrical world of America. Both men have just finished tours of Eastern Asia investigating industrial fields which this part of the world offers the electrical industry. Mr. Rice will sail tomorrow for the United States, while Mr. Swope left Yokohama for America, via Vancouver, yesterday noon. Below is a sketch of the two men and their accomplishments.

* * *

When it was announced that Mr. Rice would receive the Third Order of Meriti with the Middle Cordon of the Rising Sun, the "Yorodzu Choho" said:

"Mr. Rice, the head of the General Electric Co., the largest of the kind in America with a capital of over 225,000,000 yen, is 56 years of age. He is the President of the American Institute of Electrical Engineers. He is one of the best friends Japan can ever have in America and countless number of students, Government officials and engineers, have received his direct attention in the study of electricity at his works.

"He is also directly instrumental for the development of the electrical industry in Japan, by taking a part in the working of the Shibaura Engineering Works and the Tokyo Electric Company."

(From the Peking *Daily News*, Peking, China, October [illegible] 1917)

DINNER TO MR. E. W. RICE

Mr. Carey as Host Yesterday. Entertainment by Officials

Mr. W. F. Carey, of the Siems-Carey Company, gave a dinner to Mr. E. W. Rice, President of the American General Electric Company of New York, last evening. Many Cabinet Ministers and Vice-Ministers also attended. The function was a great success.

Tonight, Mr. Hsiung, Hsi-ling, former Prime Minister of Agriculture and Commerce, Mr. Chang Kwo-Kan, and Mr. Liang Chi-chiao, Minister of Finance, will give a dinner in honor of Mr. Rice in the new building of the Ministry of Foreign Affairs.

Mr. Rice was introduced to all the Cabinet Ministers by Mr. Wei Yih, a member of the Ministry of Finance, and Secretary of the Directorate-General of Conservancy and Flood Relief, of which Mr. Hsiung Hsi-ling is Director-General. He saw Minister Liang Chi-chiao on Wednesday and they discussed the financial situation of the country. Mr. Rice is a great financier, and wields much influence in his own country. As reported before, since the visit of Judge Gary, another important American financier, he is the second captain of industry that has visited Peking within the year. It is said that Mr Rice is even more influential than Judge Gary, President of the Steel Corporation in New York.

Mr. and Mrs. Rice expect to stay in Peking for a few more days. More entertainments to be given in their honor have been planned by Chinese officials. Mr Rice's visit and the recent visit of Admiral Knight, Commander of the United States Asiatic Fleet, who left for Japan a week ago, are bound further to strengthen the friendly relations between China and America. Several high Chinese officials have expressed their wish to a representative of the "Peking Daily News" that more Americans holding influential positions in their own country should visit China, as they believe that such visits tend to remove much ignorance [illegible] United States relative to conditions in this country.

E. W. RICE AND PARTY END ADVENTUROUS TRIP THROUGH FLOODED DISTRICT

President of General Electric and Ladies Travel on Donkeys and Han[illegible]

A [illegible] Mr. E. W. Rice, Jr., President [illegible] General Electric Company of New York, Mrs. H. Parsons, sister of Mr. Burchard, Vice-President of the General Electric Company, Mr. Geo. P. Hart, President of the great Stanley Works of New Britain, Conn., and Mr. W. A. Mitchell, President of the American Chamber of Commerce of Tientsin, wandered joyfully into town last night after a long and adventurous trip from Peking.

The party left the capital last Saturday at midnight in a private car provided by the Vice-Minister of Communications. They were traveling down over the Peking-Hankow line. All went well until they got to Shin Le-hsien on Sunday morning. Here they ran across the path of the flood or rather the path ran across them. Undaunted by the devastation they set out for Lin Hsin-shwang, traveling by sampan, donkeys, work train, hand car and baggage car and crossing one stream on a pontoon bridge.

At the van of the cavalcade were Chinese carrying flags bearing the legend: "Ladies! Special guests of the Peking-Hankow Railway." At Chung-chow they connected with the new Langhai line and made their way to Hsuchowfu, where they rested Tuesday night, departing for Shanghai yesterday morning.

Mr. Rice said last night that they met with perfect courtesy everywhere. He is sailing for Manila tomorrow but plans to make another trip to China in the near future.

Mr. Mitchell, who has had a not-to-be-forgotten experience with the floods at Tientsin, says that their seriousness cannot be exaggerated. Fifteen thousand square miles to the south and west of Tientsin is under from three to ten feet of water.

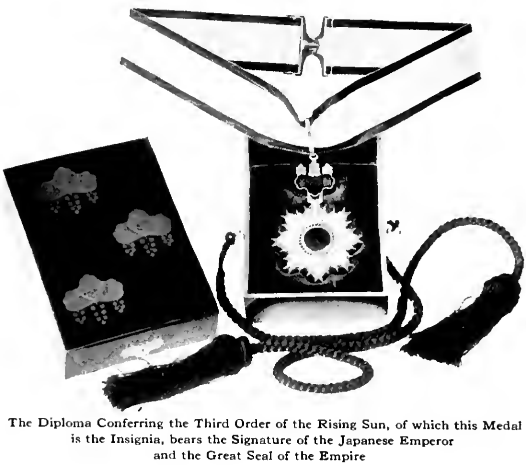
(From the Manila *Times*, Manila Island of Luzon, P. I., Oct. 23, 1917)

ENTERTAIN RICE PARTY FRIDAY

Merchants' Assn. will Give Dinner Dance at Hotel

A dinner is to be given in honor of the Rice party at the Manila Hotel on Friday evening at eight o'clock, October 26th, under the auspicies of the Manila Merchants Association.

The members of the party are to be guests of the Association members and their friends at the Manila Hotel, and following the dinner, a dance will be held. A short speech of welcome in behalf of the Manila Merchants' Association will be delivered by Victoriano Yamzon.



The Diploma Conferring the Third Order of the Rising Sun, of which this Medal is the Insignia, bears the Signature of the Japanese Emperor and the Great Seal of the Empire

The Automobile Electric Kitchen

By Anson S. Rice
Duparquet, Huot & Moneuse Co.

The equipment described in this article would serve a long-felt want in many instances, such as at hastily organized labor camps, etc., but its principal present interest is in connection with its use at army encampments. The kitchen is mobile and entirely self-contained, and its construction is such that cooking operations may be conducted while under way. The advantages of cooking by electricity are well known; fire risks are reduced to a minimum, control of temperature is effected by the turning of a switch, and the quality of the food is superior to that prepared by any other method. The capabilities of the outfit are well demonstrated by tests made at the direction of government officials, the results of which are given at the conclusion of the article.—Editor.

The automobile electric kitchen described in this article was designed and built by the Duparquet, Huot & Moneuse Co., primarily for army use. It consists of a standard Ford touring car and Smith Form-A-Truck attachment on which are mounted a small direct-current generator and a number of insulated cooking compartments. The cooking compartments are fitted with electric heating units and provided with passages for the exhaust gases from the engine, the heat from which materially assists in the cooking operations.

The vehicle body is 10 feet long and 4 feet wide, and is fitted with a canvas top of the regulation army type, with sides extending to protect the operator from the weather. Eighteen-inch hinged side platforms are fitted which, when in position, provide access to all cooking departments, and when closed lie within the clearance line of the vehicle.

The generator is of standard General Electric construction, totally enclosed, and is rated 6½ kw., 125 volts, 1800 r.p.m., and is designed for continuous operation at rated load. The generator is driven from the transmission shaft of the automobile by silent chain. The driving shaft is connected to either the generator driving sprocket or to the rear axle of the car by means of a positive clutch mounted on the transmission shaft and supported by roller bearings on each side. This clutch is operated by a lever which in one position engages the generator, and in the opposite position the driving mechanism of the automobile. Voltage is judged by pilot lamp and regulated by the speed of the engine, no instruments being necessary. Protection against short circuit and overload is provided by a General Electric overload circuit breaker and fuses. A larger, and for many purposes more desirable, equipment employing a 12-kw. generator, could be mounted on a 2-ton truck.

Water for cooling the engine is contained in a heavy galvanized steel tank located in an insulated compartment at the rear of the vehicle. The water is circulated through the engine and radiator by means of a centrifugal pump mounted on the engine. In the demonstrations described later, 80 gallons of water was raised from 60 degrees to the boiling point in less than two hours. This cooling water may be used for culinary purposes, if the pipes, radiator, etc., are occasionally flushed out and cleaned.

Fireless cooking is accomplished through the heat-retaining properties of the insulation. This insulation is superior to that of the ordinary fireless cooker in the amount and quality of material used, and a further advantage of this equipment is that additional heat, either from the electric units or the engine exhaust, can be applied at any time to hasten the process. No hot disks or similar devices are required. When the cookers are nearly filled and the contents are brought to the boiling point a cooking temperature will be maintained for 26 hours. In domestic types of fireless cookers

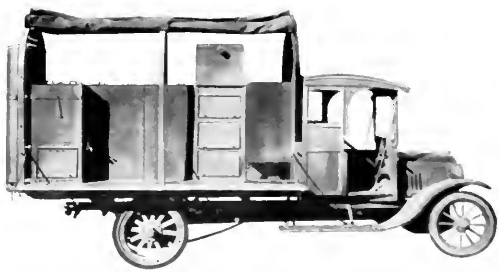


Fig. 1. Automobile Electric Kitchen showing Cooking Compartments and Water Tank (at rear) Mounted on Truck Platform

a cooking temperature is retained for only about five hours.

Frying, Roasting and Baking Compartment

This compartment is 18 in. wide, 18 in. high, and 24 in. deep. It is provided with six removable racks and will hold six shallow baking pans or two large roasting pans. It is heated by four 9 in. by 12 in. 1600-watt cast-iron electric hot plates. The sides, top, and doors are heavily insulated. The doors are supported by pin hinges and can be quickly removed when the oven bottom is to be used for frying or making griddle cakes.

All methods of cooking, with the exception of broiling, have been provided for. Broiling can be done by installing an electric broiler in the top of the oven. In the model such a broiler was used for grilling frankfurters, etc., while crullers were fried on the oven bottom at the same time.

Underneath the oven, and heated by it, is a warming closet large enough to hold roasting pans. This closet is fitted with drop doors on both sides for serving purposes. Under the warming closet are located the switches, circuit breaker, and all fuses for heating circuits.

Fireless Cooker Compartments

There are four fireless cooker compartments, each having a capacity of 30 gallons. The insulation, which is two inches thick, is fireproof, self-supporting, light in weight, and the most efficient of any commercial insulation known. Monel metal was selected for the fittings, interiors, and insulated covers because of its strength and non-corrodible qualities; it is undoubtedly the best metal obtainable for cooking purposes. These compartments have semi-hemispherical bottoms to facilitate cleaning and draining, and are provided with draw-off faucets. A special screw plug is fitted which can be replaced with a strainer when desired. All seams are welded or silver soldered, and if heat is accidently turned on, with no water in the vessel, no damage will result. A closet with drop door is located under each vessel for storing utensils. These compartments are heated by the engine exhaust, and by two General Electric sheath wire units wound on steel supports, combining strength with light weight. No porcelain parts, lava, or other fragile substance is used for insulating these units.

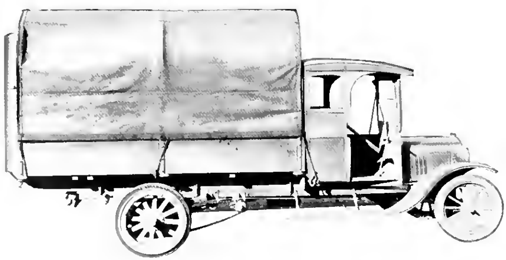


Fig. 2. Automobile Electric Kitchen with Regulation Army Type Canvas Covering in Position

Uses

A single large equipment, or two smaller equipments, will easily prepare the regulation rations, consisting of four courses, with coffee, for a company of 250 men, or coffee and one pint each of stew for 500 men. In army camps or elsewhere where regular ranges are available this equipment can be advantageously used as an auxiliary. For instance, it may be employed for making stews and cooking vegetables and cereals by the fireless cooker method, or for making coffee or French frying—for all of which purposes it would be superior to a camp range. It would not be necessary to supplement the range by cooking in galvanized ash cans over wood fires or similar methods, as is now practiced in some of the camps. Where electric current is available all of the equipment, with the exception of the hot water tanks, can be operated without running the engine or generator. For stews, the superiority of the fireless cooker method is unquestionable. It is peculiarly adapted for all gelatinous meat, such as knuckles, head and feet, and for all tough fibrous meats, because of the fact that long continued moderate heat in the presence of moisture is the best way of converting gelatine and tough fiber into edibles. These preparations will not only be edible but palatable, thus preventing the great waste which is suffered when meat is not properly cooked. It is a well-known fact that when meat is roasted in an electric oven it is superior in flavor and undergoes considerably less shrinkage than when roasted in a coal or gas range.

All of the fireless cooking compartments are adapted for French frying in deep fat or oil. Croquettes and similar preparations are much nicer when cooked in this way, as are also many kinds of fish. French fried potatoes, bacon, salt pork, doughnuts and crullers, hash balls, etc., can be improved by cooking in this manner.

The arrangement of the compartments permits easy clarifying of the oil and fat so that it can be used over and over again. The amount of food which can be cooked in a short time with this equipment will supply a greater number of persons than appears obvious from the rated capacity of the kitchen.

A special Monel metal dipping basket is provided for French frying and for steaming meats, puddings vegetables, etc.

For making coffee special close-weave cloth leeches are furnished, which can be used in any of the compartments. Coffee made in this way is superior to that produced by the usual methods common in camps, where a large pot of coarse ground coffee is placed on the range and allowed to simmer for several hours.

Good cooking requires patience, experience, good judgment, and a knowledge of the effects of moist and dry heat upon certain foods. Hastily and poorly prepared dishes cannot be placed in the fireless cooking compartments and taken out as delicious triumphs of the culinary art. The fireless method of cooking, however, requires less attention than the common method and there is no danger of burning the food if ordinary care is taken when applying the initial heat.

High efficiency is obtained by employing the exhaust heat from the engine to assist in the cooking operations and by utilizing the heat ordinarily wasted in the engine radiator to heat the water in the hot water tanks. The ultimate economy of the equipment will depend upon the conditions under which it is operated. For instance, when traveling on the road the exhaust and other heat from the engine is a by-product or waste and may be figured to cost nothing. On the model described the consumption was 5½ to 6 quarts of gasolene an hour when running the generator at its full rated load of 6½ kw.

Because of the efficient insulation of all cooking compartments it is necessary to operate the generator at its full capacity for only a short time. In ordinary cooking operations the fuel consumption will, of course, also depend upon the extent to which the operator takes advantage of the fireless cookers. Cooking can be done as long as the engine runs. In case of complete breakdown current can be supplied from the generator of a second car, if this is available, and the exhaust heat from this car used to continue the cooking operations, thus keeping both kitchens in service. The second car could also tow the disabled one, if necessary.

The electric generator could also be used to supply light or power for any purpose within its capacity. For instance, the 6½-kw. generator could supply current for 246 25-watt lamps or 650 10-watt lamps, or

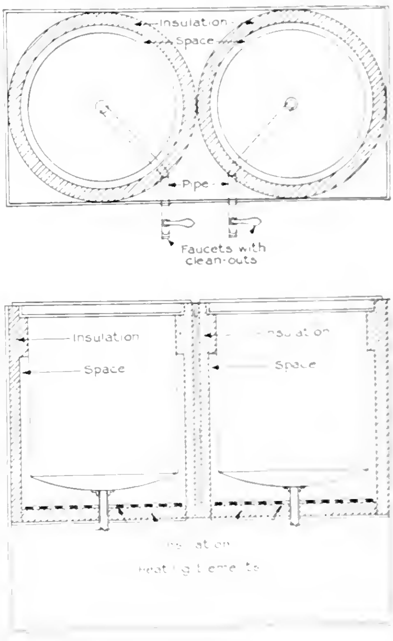


Fig. 3. Plan and Elevation of Fireless Cooker Compartment

power for the electrical equipment of a field hospital for X-ray work, sterilizing, etc.

While performing this service the exhaust heat could be employed for cooking and heating the water. The generator on the larger equipment could, of course, furnish correspondingly more power.

In freezing weather, when the engine is not running, it will be necessary to close the valve at the bottom of the hot water tank and to drain all water from the pipes, pump, engine, and radiator. The water in the tanks will retain its heat for a considerable length of time. A non-freezing mixture could be put in the tanks if desired, but this, of course, should not be poisonous.

In general, the entire equipment is constructed of the best material and is well made. Special attention has been directed toward making the apparatus easy of operation and as near fool-proof as possible. Anyone having the knowledge and skill necessary to drive an automobile can easily operate this kitchen. The heating elements are constructed to withstand excessive voltages due to accidental speeding up and are arranged so as to be easily replaced when necessary.

TESTS AT GOVERNORS' ISLAND MAJOR QUAY'S DIVISION

First Morning Demonstration

Operators were requested to furnish coffee and stew for dinner. Started with everything cold at 9 a.m., using electric and exhaust heat on one 27-gallon kettle. Stew (lamb) was cooking, and kettle sufficiently heated to permit all heat to be shut off at 10:20 a.m. Stew continued to cook (fireless cooking principle) until noon, when it was served to 110 men. (Partial capacity one kettle only.)

During this time exhaust heat only was turned into one other kettle containing about 18 gallons of water. At 10:22 electric heat was also turned on. Water was boiling and ready for coffee at 10:35 a.m. Served to 250 men at dinner. (Partial capacity one kettle only.)

Afternoon Demonstration

At 3.25 electric heat only was turned on oven. At 3.35 about 60 lbs. of beef was placed therein. Two roast pans of about 18 in. by 24 in. were used. At 5 p.m. first pan was removed, meat being thoroughly cooked. At 5.15 p.m. second pan was removed, the fifteen minutes difference being due to larger pieces of meat. All of the meat was well cooked (according to army cook) with the exception of one very large piece, which was then placed in the coal range oven. It could have been replaced in the electric oven for another few minutes had the cook wished, as the electric oven was at a much higher temperature than the coal range.

From 5.05 p.m. to 7.40 p.m. generator furnished two mess buildings with 40 lights, 25 watts, 120 volts. (Small fraction of generator.)

During the demonstration about 120 gals. of hot water was heated and used in mess hall and kitchen.

Weather conditions were bad: very cold, drizzling rain, with cold and constant wind. Average temperature, 45 degrees F.

Second Morning Demonstration

Cooking started at 9.10 a.m. All heat turned off at 11.40 a.m. Stew was served to 216 men and coffee to 246 men at 12 m. (About half full capacity.)

Afternoon Demonstration

At 1.50 p.m. operators were requested to have coffee ready for 300 men at 4 p.m. At 2.30 p.m. operators were informed that a change had been made in plans, and it was to be served at 3 p.m. At that hour 40 gals. was served and wth the stored heat (fireless cooker) 20 gals. more was made for supper.

These demonstrations did not give an opportunity to demonstrate the entire purpose of the kitchen, as the fireless cooking method was used very little. In order to do this it would be necessary to have a prearranged menu, at which time these features could be properly brought out.

If the one-ton truck equipments were used, probably two of them would be necessary for a company of 250 men. The advantages would be the comparative simplicity of the trucks, and the fact that in case of breakdown of one engine current could be supplied from the other generator; or one truck could if necessary tow the other. The amount of equipment is limited by the size of the truck.

The 2-ton truck equipment should easily handle rations for a company of 250 men, or coffee and stew for 500.

Obviously the various compartments could be changed as might seem necessary, or larger equipments could be built. Probably a 5-ton truck equipment would take care of 1000 men or more.

The Capabilities and Economies of the One-man Light-weight Safety Car*

By J. C. Thirlwall

Railway and Traction Engineering Department, General Electric Company

The light-weight safety car was developed to furnish the public an improved service at a decreased cost to the operating company. In the introduction of the following article are set forth the factors which led up to the design of the particular type of car described. Illustrations of the car and of the more important parts of its equipment are included. The latter part of the article analyzes the comparative service, operation, and cost of the new and the older types of car on a typical road; and the results are greatly in favor of the light-weight safety car.—Editor.

When the jitneys first invaded Texas some two or three years ago, the author in company with C. O. Birney of the Stone & Webster organization made exhaustive studies of the situation and observed that: when a street car came along where a crowd was gathered a great majority boarded the car; however, when a car was not in sight and a steady stream of jitneys came rolling by, the average person took the first vehicle going in his direction regardless of any other consideration. Careful study, however, indicated that the question of speed entered into the situation to a large extent. The short-haul rider took the first vehicle passing. The long-haul rider would take a jitney in preference to the street car in order to save time in getting to his destination.

Light-weight Safety Car in Bellingham, Washington

The average rider taking a street car that makes eight to nine miles an hour will require something over twenty minutes to go three miles. A jitney with its speed of 13 to 14 miles an hour will make the distance in 13 to 14 minutes. Allowing for a wait of two minutes for the jitney and a possible ten minutes for the street car, the time required for the respective trips would be 16 and 31 minutes. These conditions led Western roads to adopt the safety car, a car of high speed which is very essential in meeting jitney competition. This speed was attained by cutting down the size of the unit to reduce the number of passengers (thereby automatically decreasing the number of stopping places) and by constructing a unit that could be accelerated freely and braked rapidly in order to secure the highest possible schedule speed in frequent stop service. The acceleration of the Birney safety car is more rapid than the average operator of double-truck cars believes possible. Rates of acceleration as high as $2\frac{1}{2}$ to 3 m.p.h.p.s. are frequently used and schedules in several cities, where these cars have been installed, are based on average rates of $2\frac{1}{2}$ m.p.h.p.s. both for acceleration and braking. The highest average rate of acceleration with double-truck cars in city service is about a mile and three-quarters. Anything more rapid than this with a double-truck car throws the passengers around on account of the pendulum effect due to swinging bolsters when a heavy body is accelerated. It causes discomfort and, where there is a drop platform, might cause accidents in many cases.

The low-wheel type of car with an extremely light body, flush platform, and low center of gravity, with the body tied rigidly to the truck so that there can be no pendulum effect, can be smoothly accelerated and braked at high rates of speed. The speed that the public demands is thus supplied in the light-weight safety car which may not be quite as fast as the automobile on long runs but is a close competitor.

Frequency of service is another important factor. Where headways are 10, 12, 15, or 20 minutes, as they are in many cities—even on

*Extract of a talk before the New England St. Ry. Club, Boston, Mass., October 25, 1917.

many lines of the largest cities it is found that the standard car of today cannot be profitably operated on shorter headways—a great many people walk, especially up to the 15-minute or longer headways. A person can walk a mile in fifteen minutes and a tremendous pro-

Light Weight, 25-h.p. Motor Designed for the Light-weight Safety Car

portion of short-haul riders are not secured when headways are lengthened to that point.

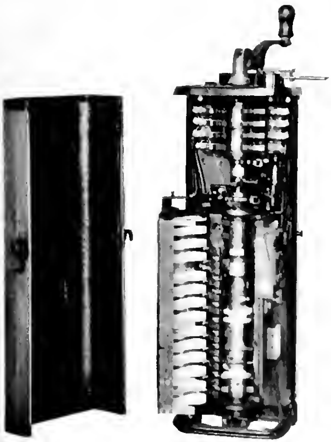
The new type of car is cheaper to operate. Its platform wage, its power consumption, and its maintenance charges for equipment and track are so much less than for older types of cars that it is possible for a given amount of money to run twice as many car miles. In other words, for a given amount of money spent in operating cost, the public can be given 100 per cent more service with the new type of car. In one fairly large city of the West, the *Electric Railway Journal* reports that an increase of 100 per cent in service resulted in an increase of 100 per cent earnings. Each car added to the run earned just as much as every car had previously.

The Stone & Webster organization has studied this question more than any other group of railway operators in the country and apparently aims for an improved service which runs from 40 to 50 per cent. That is to say, about so many more cars per hour pass any given point. To give 50 per cent more service requires, with the additional speed of the cars, approximately one-third more cars in operation on a given line. After giving 50 per cent more service it has been found without exception that the operating costs are still materially reduced, running from 20 to 30 per cent less than with the heavier cars; the financial results have shown a very material increase in the amount of riding and consequently in the volume of receipts. The operating ratio has thus been reduced from about 65 to 70 per cent to about 45 to 50 per cent, leaving the net revenue tremendously improved.

A fairly typical instance was recently worked out for a road in the middle West where conditions are fairly typical of the average manufacturing town or city in the East. This city is a manufacturing community in Ohio with an extremely heavy rush-hour traffic and a fairly light riding the remainder of the day, which is typical of some lines in every city. The operating costs were fairly typical of the average road as well as the method of operation, etc. This line is 3½ miles long and double-truck cars are now used, these seating forty-four people and weighing 44,000 pounds fully equipped. The running time for the round trip of seven miles is 50 minutes or a little over eight miles an hour. The all-day headway is ten minutes, requiring five cars. It was proposed to replace these cars with the new light-weight type seating 32 people and weighing 13,000 pounds, thus reducing the weight per seat from 900 to 400 pounds

Control and Air Brake Equipment Installed on Light-weight Safety Car which would cut down the power per car mile 60 per cent. This change would also cut the cost of maintenance of track and equipment. It was suggested that a seven-minute headway be operated in place of the present ten-minute headway, a six-minute headway during the rush hour instead of the ten-minute, and a running time of 42 minutes in place of 60 which is a very conservative estimate of the possibilities since it is practicable under most city conditions to obtain schedule speeds of 10 to 11 miles an hour with these cars. With this arrangement one more car would be required during the day and two more during the rush hour. The seating capacity would be practically identical with that obtained at present, thus giving the public fully the equivalent of the present service.

The number of car hours per day would be increased from 95 to 118, and the number of car miles, on account of the higher schedule speed, would be increased from 793 to 1173, an increase of 48 per cent which is a direct measure of the improved service that the public would receive. On the basis of the operator of the one-man cars



Series-parallel Controller for Use on the Light-weight Car

receiving somewhat increased wages, the annual cost of platform labor would drop from $18,724 to $12,891, a decrease of about 33 per cent.

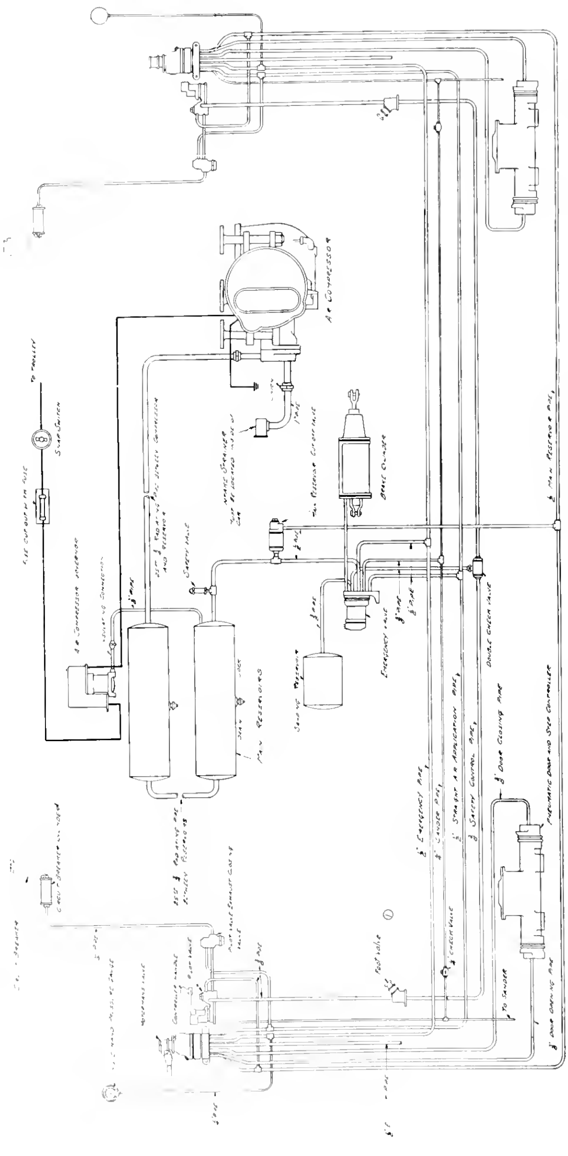
The cost of power on this property is a little above the average on account of the road being situated a long distance from the central station; the extremely heavy line drop makes the cost of delivered power about 2 cents per kw-hr. The present rolling stock with a fairly low-speed schedule is taking about 2½ kw-hr. per car mile, so that the energy is costing 5

Motor-driven Air Compressor for Supplying Air to Operate the Brakes, Doors, Steps, and Sanders

cents per car-mile. The proposed new car would take about 1 kw-hr. under the same conditions, which means a cost of 2 cents per car mile or a reduction of 60 per cent. The maintenance of way at present costs 1.3 cents per car mile. With a reduction of two-thirds—nearly 70 per cent—in the weight of the cars used, a very conservative estimate would be a reduction of at least one-half the cost of maintenance per car mile; *i.e.*, 0.6 cents per car mile.

Maintenance of equipment on the cars now in service is probably higher than the average, approximately 3 cents per car mile. The cars are about 18 or 20 years old and are equipped with an obsolete type of motor, four motors being used instead of two as on the new car. It has been figured that a reduction in maintenance costs could be made from 3 cents at present to 0.8 cents for the new cars.

Summing up, the total operating cost for the system would drop from $52,454 to $34,449 or more than $18,000 which is equivalent to 30 per cent. The present receipts are $69,166 and the operating ratio is 71 per cent. With the 50 per cent more service which the new equipment would furnish there should be at least 20 per cent more riding, making a new gross income of $83,000 and increasing the present $17,000 net income to $44,000. To accomplish these results would require eight cars, seven being required for rush-hour service and one as a spare. The cost of eight cars at present would be about $45,000.



Connection Diagram for Air Brake Equipment of Light-weight Safety Car

This return of $32,000 on an investment of $45,000 means that the cars would pay for themselves in eighteen months; or in another way we might say that the increase in fixed charges incurred by the purchase of eight new cars (allowing 15 per cent to cover interest, depreciation, insurance, and taxes) would be only about $7,000 leaving a net profit of $42,000 per annum on a line that is now showing only $17,000 above operating costs. In other words, the change-over would turn a line that is probably not paying one cent of dividends into a very good dividend-paying proposition.

Similar results could be shown in almost every city in the country. An official of one of the biggest systems in New York City has made the statement that he believed that one-third of the service could be handled by this light-weight car and certainly no city in the United States has more congestion than New York.

In conclusion, it should not be forgotten that there is an even bigger and more important question than the financial side. The nation is calling for men and we must conserve man-power. The nation is trying to conserve its natural resources, particularly coal. Nothing that we can do will cut down the coal consumed by the transportation industry so much as the adoption of this type of car. It so greatly reduces the power consumption per passenger handled that in the long run the amount of coal burned at the power station is very much less, and a saving in this respect is of vital interest to the entire nation.

Standardized Flexible Distributing Systems in Industrial Plants

PART II. APPLICATION

By Bassett Jones

Electrical Engineer, Associated with Henry C. Meyer, Jr., New York City

The first installment of this article, which was published in our March issue, outlined the method that has been evolved by the author for determining in advance the power requirements in industrial plants, and the principles of the system of installing a flexible distributing system to take care of these requirements. The concluding installment describes the application of this system to a new factory of the Sprague Electric Works at Watsessing, N. J. As we have previously pointed out, standardization in this line of work is fully as practicable and desirable as standardization in the generation and control of electric power, and it would seem that Mr. Jones has taken a big step forward in the fulfillment of this desideratum.—Editor.

Power

The study outlined in Part I was undertaken with a view to determining the best method of electrically equipping a new building of the Sprague Electric Works in Bloomfield, New Jersey. It was argued that the factory of a manufacturer making all the multifarious apparatus and devices used for tool drive, motor control, and the construction of distributing and lighting systems should present an example of the most modern, practical, and economical methods of using such equipment. It should not be remembered, as is so frequently the case, in connection with the adage of the cobbler's children. Fortunately, during the construction of this building it was possible to partially apply the same method to the building now used by the Switchboard Department in Philadelphia. In so far as was possible, and in view of the fact that the Philadelphia building was practically completed structurally before it was taken over, these two buildings represent the application of a standardized distributing system. Generally, the various parts and assembly groups in the two buildings are identical and interchangeable.

Furthermore, it should be stated that the writer is in accord with both the Switchboard Department and the Industrial Control Department as to the importance and value of "dead front, safety first" equipment. This will account for several features embodied in the design. In the course of ordinary operation it should be impossible to accidently touch a "live" part anywhere, from the power house switchboard to the motor on the tool.

A typical floor plan, showing the floor distribution for power, and the tools in one department connected to the tool cut-out boxes on the columns, is given in Fig. 6-A. This plan also shows a typical section of the underfloor passages and floor trenches; A as actually used, B located as experience has shown would have saved some of the small amount of floor cutting necessary. As tools are commonly grouped on the column axes across the building a passage or duct on these axes is more generally useful than one in the center of the bays.

On the basis of what has been said previously regarding location of risers, two riser points are required in this building. They are located against "tower" walls, so that the switchboard at the foot of the riser will be situated out of the way in the tower. Also, because of proximity to passage-ways, stairs, elevator openings and doors, these walls will be free from tools.

It is probable that this will be a fairly average diversified machine shop, therefore, on the basis of 2.25 average watts per sq. ft. total floor area, two No. 1-0 mains per floor are required. They are located near the interior columns with tap boxes at each column as indicated. As a preliminary arrangement, each main is fed by a No. 1-0 feed from each riser point, the [illegible] junction therefore being normally provided with two 200-ampere circuit breakers. The breakers are not installed [illegible] until the actual load distribution is known. Then, for instance, three breakers may be installed [illegible]. In the case where [illegible] a reinforcing feeder to some [illegible] is required [illegible] conditions.

What has been said [illegible] breakers is also true [illegible]

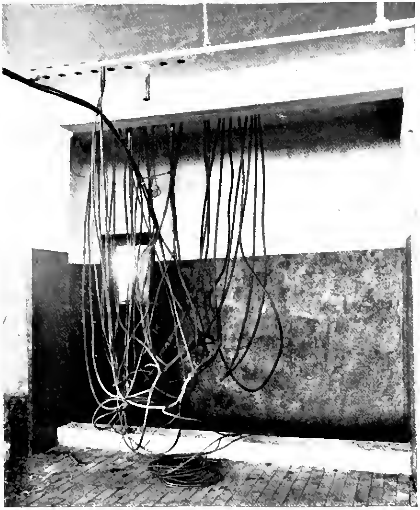


Fig. 7. Looking into Switchboard Room Through Switchboard Opening

Fig. 8. Foot of Riser Shaft

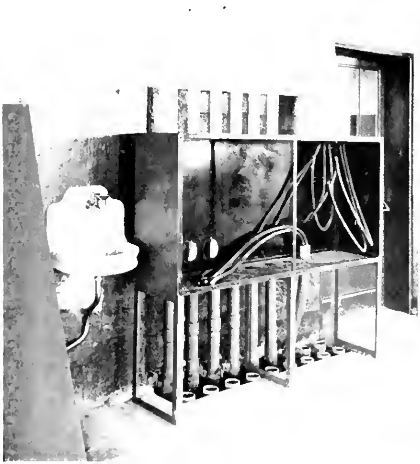


Fig. 9. Typical Floor Power Riser Junction

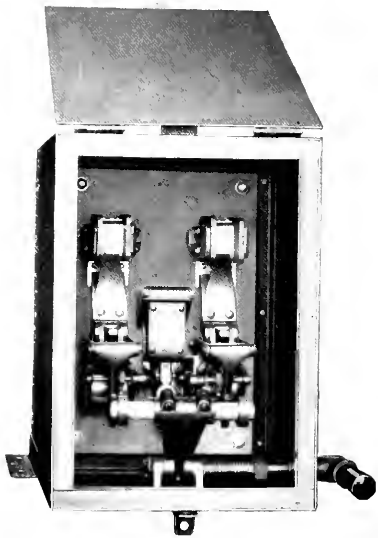
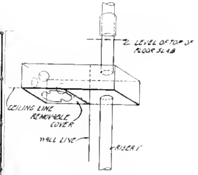


Fig. 10. Safety Circuit Breaker



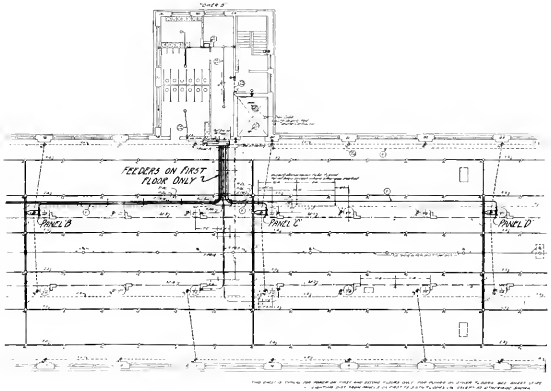
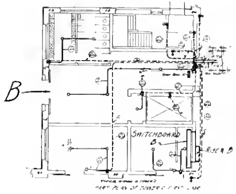


Fig 6-B Typical Floor Lighting Distribution



Typical Lighting Distribution in Tower C

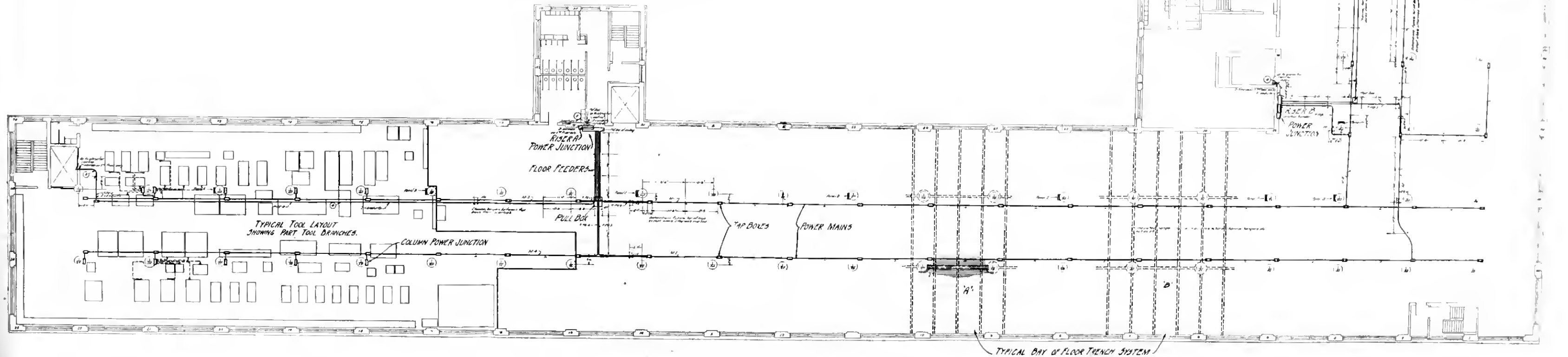


Fig. 6-A Typical Floor Plan showing Floor Distribution for Power

copper is No. 4/0, all riser copper 300,000 c.m. The necessary average amount is ordered and installed where required. Over some dead areas no copper will be necessary—over manufacturing areas the average watts per sq. foot may rise to 4.5 or even more. Just how the copper should be arranged can be quickly determined in the manner previously described from the tool layouts when received.

Originally it was thought that no power would be required on the sixth floor. Therefore only hanger inserts were installed. Not even floor junctions or riser copper was ordered. At present one end of the floor fed from riser A is used for manufacturing. The copper required was simply not installed in some region of some other floor, which by reason of this change is now used for stock and packing. Thus the averages work out as expected.

The original allowance for riser copper was determined on the basis of a 300,000 c.m. riser from the first floor switchboards to each floor junction, except on the sixth. Some of these have since been increased. At the present time five sets of riser feeders run up riser A to the fifth floor, all the extra feeders being for special equipment, the load demand having been decided upon after many tools were in operation. The controller test department, occupying about 6,000 sq. ft. and finally located on this floor, required about 200 kw. Baking ovens distributed on three floors required about 300 kw. more.

In practically every other case the original riser feeders have proven to be of proper size. In two cases other than the one mentioned, they have been duplicated.

Having thus installed extra riser feeders, it is necessary to provide additional control for them. This is accomplished by installing the necessary additional circuit breakers on the riser switchboards, which operation is made simple and possible by the fact that the board itself is standardized, and the breakers used are only of two sizes, both occupying the same amount of space.

Details of Installation

Let us now begin at the foot of the riser and follow back over the system to the tools, with photographs to help our understanding, and remembering the general diagram given in Fig. 4.

In Fig. 7, from the first floor hallway in one of the towers, we are looking into the switchboard room through the hole which will later receive the switchboard at the foot of riser A. Passing out of the tower into the main first floor of the shop we look back, in Fig. 8, to the foot of riser B. Here we see the riser conduits passing through the second floor nipples. (Note Fig. 5.) Near the first floor ceiling they pass through a hole in the wall into the switchboard room. We also see the beginning of the first floor distribution originating at the floor junction—in the photograph only a steel box on legs. The circuit breakers have not been mounted.

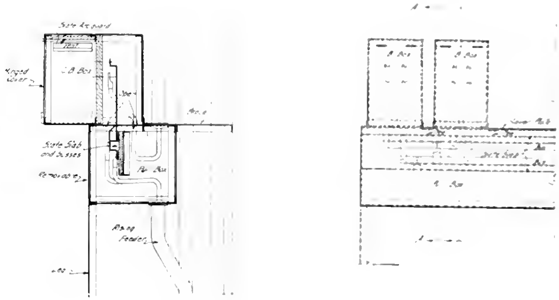


Fig. 11. General Arrangement of Power Junctions

Passing up the riser to a typical floor in Fig. 9 we are looking closely at one of the floor junctions. Here we see the riser conduits to floors above passing back of the box and, below it, the floor nipples through which they pass. Eventually this box will contain a junction bus panel, and on it will be set circuit breaker boxes. The circuit breakers themselves are dead-front safety-first, and incidentally, the first time such breakers have been used. A character drawing of a complete floor junction is shown in Fig. 11.

A Dead Front Safety First Circuit Breaker and Switchboard

The general appearance of the circuit breaker is shown in Fig. 10. It is a standard breaker to which have been added arc blow-outs and a special operating rocker mechanism, and

Fig. 12. View of General Floor Power Distribution

Fig. 13. Tool Making Department, Sprague Works, in Operation

Fig. 14. General View of Power Cutout Boxes, Sprague Works

Fig. 15. Standard Lighting Panel Separate from Riser. Fed from Cutout Box Mounted on Nearest Riser Tap Box

is enclosed in a locked steel box. The operating handle protrudes through the side of the box. The handle can be interlocked with the cover so that the cover can not be opened unless the breaker is open.

The riser switchboard to be installed in the opening into the switchboard room (Fig. 7) is shown in Fig. 15-A. It is built up in standard circuit breaker and dead front safety-first knife switch units as needed.

When the board is assembled with switches and breakers it presents an unbroken face of sheet steel on which are no live parts. Such a board can be installed, unguarded, with safety in open shop spaces if desired.

Floor Distribution

Now let us step back from the riser to the far row of columns. Looking toward the riser in the Bloomfield building, we see in Fig. 13 the floor feeds extending out to the mains, and the mains running both ways. The main conduits and tap boxes are evident as this picture was purposely taken before the painting had been completed.

It is interesting that this particular view shows a floor which, at the time the picture was taken, was structurally completed with floors laid. Yet the writer does not know what load will be required on this floor, how it will be distributed, or where any tools will be placed. No more difficulty will be experienced in installing tool connections than on any of the other floors where manufacturing is now in progress.

A floor in the Bloomfield building where tools are installed and operating is shown in Fig. 13. This is a part of the department whose tool layout is shown in Fig. 6-A (and for which load data have been given).

When tool layouts are received and the copper in main distribution proportioned therefrom, locations of tool cutout boxes are determined and indicated, together with the tool branches (as shown in Fig. 6-A). All of this material including cut-out boxes, fuse gaps, and copper and conduit for tap and tool connections was prepared and ordered in advance by the use of averages much as the copper was averaged. The results were close to actual requirements.

These remarks are merely made to show that with this system, in emergency cases, or when delivery is bad, it is possible to order ahead and so not hold up the work when the final tool layouts and the tools actually come through.

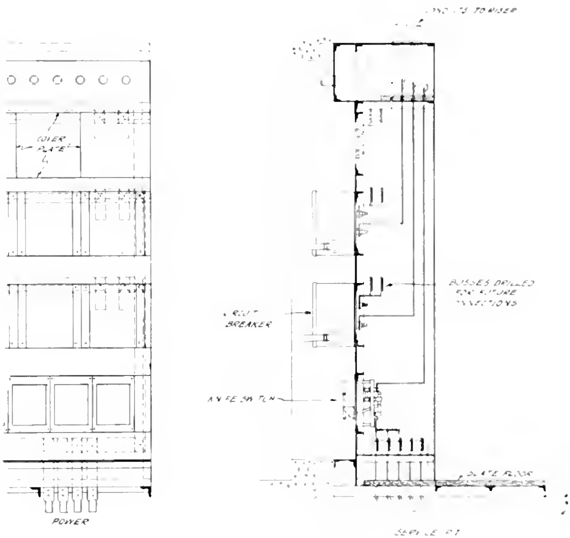


Fig. 15-A. Dead Front Safety First Built-up Switchboard

Tool Connections

Let us now start at the tap boxes in the mains and follow down to the tools.

Fig. 16 shows a typical column in the Bloomfield building. On the left hand side is a tool cut-out box and tap connection from the tap box in the main overhead.

Where a large number of tools are to be placed, a cut-out box is installed on every column (Fig. 14). In a few cases two are placed back to back on a single column. Should revisions occur, the boxes and their tap connections may be moved to other columns and re-installed. This view shows that

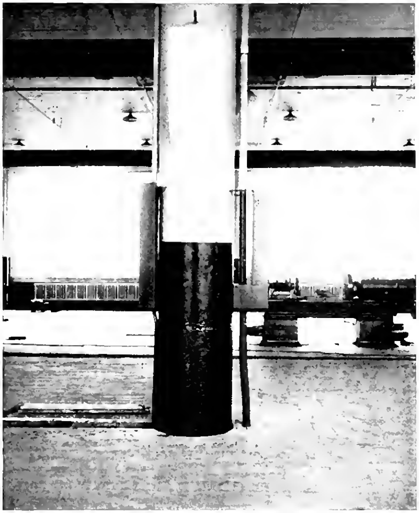


Fig. 16. Typical Column, Bloomfield Building

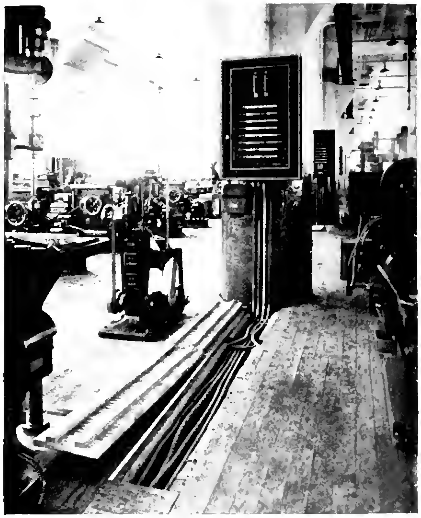


Fig. 17. Tool Connections, Sprague Works

Fig. 18 Controllers on Columns

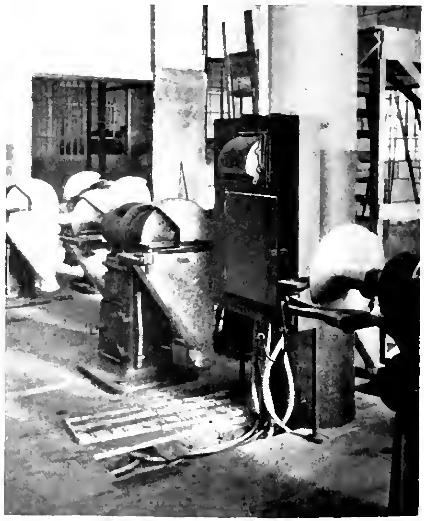


Fig. 19. Tool Connections, Philadelphia Building

some tools are placed and connected. Others are being connected, and still others are yet to come. Note that so far only one tool has been connected to the cut-out box in the immediate foreground as shown by the fact that no connections are run in the open header trench, and one connection goes around the column to the next bay back.

Fig. 17 shows a close-up of one cut-out box in the Bloomfield building with all fuse gaps installed and all connections made in rigid conduit above the floor and flexible conduit below. None of the covers have been fitted to these boxes. Note the connections entering the under floor passages. The starter for the tool nearest the column has been mounted on the column under the box as no suitable location could be found for it on the tool. Similar cases occur where the controllers are complicated and large, as shown in Fig. 18. In the Philadelphia building, as shown in Fig. 19, the flexible conduit is run up to the cut-out box. This is somewhat cheaper than using rigid conduit above the floor, but not so neat in appearance. The different methods of supporting the cut-out box are also worthy of attention. In the Philadelphia building pipe stands were used, the top of the stand being secured to the column by two hook bolts gripping the column reinforcing, the outer concrete being chipped out to permit this and later filled in. In the Bloomfield building four hook bolts, two at the top of the box and two at the bottom were used, clamping the box to the column reinforcing and also serving as braces. This method is cheaper than the pipe stand arrangement and both are cheaper than employing bands around the columns.

In the case of Fig. 20, only four connections have been made to the box, and therefore two double fuse gap slabs have not been installed. It should be noted that the busses are back of the fuse slabs so that the slabs can be easily removed. They are interchangeable between 30 and 200 ampere fuses. The main switch is a standard "dead front—safety first" type adapted to this particular arrangement.

Floor Cutting

When the location of a tool is established a single upper floor strip is cut out from the tool location back to the nearest under-floor passage, and the connection fished through. See Fig. 21. The under floor is then grooved, the upper floor strip notched where the lead is to come out and relaid. This shows about the maximum amount of floor cutting necessary. Of course, in many cases the tool comes very close to a passage or trench, when no cutting, and notching only is necessary. See Fig. 20.

The first floor at the Bloomfield building is laid with paving blocks. Here trenching did not seem feasible, so the only recourse was to make the runs from the cut-out boxes to the tools as short as possible by careful placing of the boxes. Where the conduits do not cross passage-ways they are run exposed over the floor. Across passage-ways the blocks are raised, the connections run in the resulting trench, and the blocks split and re-laid. See Fig. 22. Where the tools are near the outside walls, the boxes were set on these walls and the connections run exposed on the floors, along the walls as shown in Fig. 23.

It will be noted how neat and workmanlike is the whole appearance of the tools, starters, controllers, and their connections, shown in Figs. 17, 18, and 20. Every unit or assembly group from switchboard to starter is literally brought in a box ready to mount. There is practically no piecing together of details in the field—and all apparatus is under lock and key. No live parts are exposed, nor are there any exposed connections or leads. Leads from starters to motor terminals are run in conduit clipped to the tools, and motor terminals are protected by metal boxes, so that a hand tool or work carelessly used or dropped cannot strike a live part.

Lighting Distribution

Before the distributing system for lighting can be logically designed it is necessary to study the general form that the illuminating system will take. As will be shown later, the general illumination of factories can be so arranged that flexibility in the distributing system for lighting will not be essential to the same degree as flexibility in the distributing system for power. However, some degree of flexibility must be provided so that the general and separate control of the lighting can be arranged in different departments, wherever they may come, as well as local control in offices and other small rooms. In addition it must be possible to rearrange the lighting or provide special lighting over any area for special conditions, small part stock cases and the like with proper control. Extensions of the lighting system may be required at any time and at any place to meet such special conditions.

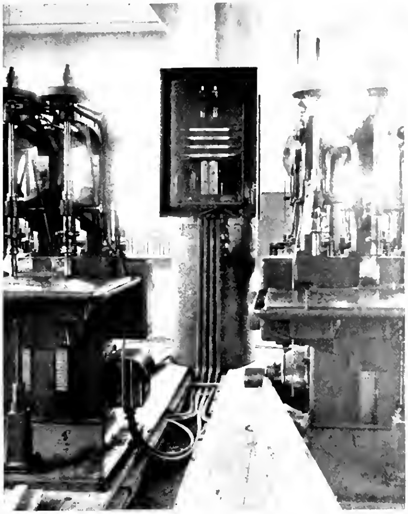


Fig. 20. Tool Connections

Fig. 21. Tool Connections

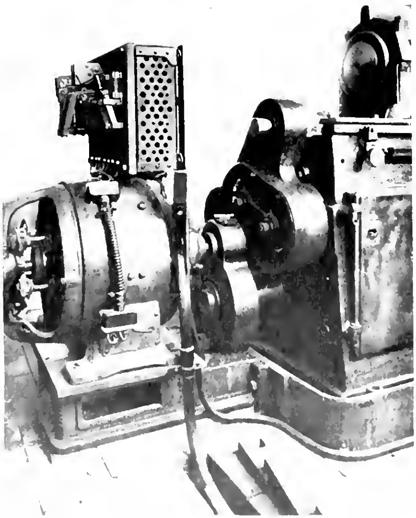


Fig. 22. Tool Connections in Block Paving Floor

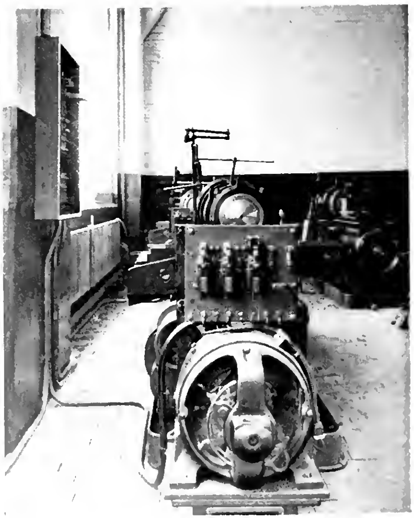


Fig. 23. Tool Connections, Run Exposed Above Floor

It is well to avoid expensive general local control of the lighting. The branch circuits should be concentrated at panel boards and controlled at these panels. Since access to the panels for this purpose must be had at all times by all manner of persons, it is advisable to make the panels dead front safety first.

It should be possible to rearrange the routing of branch circuits so that the lighting in any region may be controlled at one or more panels in that region. The common practice of locating the panels at one, or at most, a few central points, commonly at the riser shafts should be avoided. It should be possible to locate a panel at any point where it will be most convenient for the control of the circuits brought to it. In other words, it should be possible to locate a panel at any desirable point in the building.

At the same time, the panels must be so placed that ready access can be had to them, and so that the distance to the group of lights farthest away from the panel is not too great for convenience.

These considerations indicate that a multiplicity of small panels will function better than a few large panels. Then the length of the branch circuits will never be very long. At most fifteen feet of branch circuit work will cost as much as a branch circuit switch and a proportional part of the panel box.

If then, in one-story buildings use is made of a lighting main run lengthwise of the building and controlled at the riser or main switchboards, panels can be tapped off it at any point precisely as tool cut-out boxes are tapped off the power mains. It is easy to figure out how far apart the panels should be spaced so that the branch circuit work will cost less than the main and panel taps. In a building seventy-five feet wide—three bays—with four lighting outlets per bay, 100 wats per outlet, a panel every four bays, or every 100 feet generally, will save money over extending the branch circuit work. Generally speaking, the panels should be so placed that as far as possible the money invested will be about equally divided between branch circuits and panels together with their taps and the mains or risers. Receptacle circuits must also be taken into consideration.

In buildings more than one story high the taps from the lighting main on the first floor will then also become risers, spaced not over 100 ft. apart in buildings 75 feet wide. These risers may pass through tap boxes on each floor on which a panel may be mounted, or from which a tap may be run to a panel in its vicinity. This general method makes it possible to use a small one-sized panel board throughout.

Fig. 24. Standard Lighting Panel Board

There are several suitable ways of handling the branch circuit work so as to give it flexibility.

A part of the lighting distribution in the Bloomfield building is shown in Fig. 6-B. A grid of six parallel $^3/_4$-inch conduit lines is installed in the forms, two to each row of bays. The $^3/_4$-inch conduits are used so that two circuits be routed over each line. The parallel lines are tied together and to the riser tap boxes at each riser point by two 1-inch conduit lines so that circuits to the number of six can be routed home to any panel on either side of the building. Money would have been saved if the grid had been still more extended.

The conduit and outlets for the ultimate and maximum requirements are thus necessarily installed on all parts of all floors, so that no matter where the "dead" and "manufacturing" areas are finally located they can both be properly lighted, and the circuits routed so that the control over any region can be concentrated at suitably located panels.

In this building the risers are fed separately on the first floor, and are placed on every fourth column on one side of the building, sleeves being provided in the forms through the column caps for this purpose.

The necessity of this extensive grid of concealed conduits is well shown in Fig. 25, which indicates the circuit routing on the fourth floor prepared after the tool layout was received months after the conduit was necessarily all in place. Even at that, some additional conduits had to be run exposed, and in several cases the $\frac{3}{4}$-inch branch circuit conduits were not large enough to take care of the "home runs" so that to find space for them these runs had to be routed over indirect lines. On other floors, the complicated routing occurred in different regions. In some few cases local switching was necessary and was obtained by the use of ceiling pull switches mounted on outlet boxes.

Practically all of this difficulty as to final routing of branch circuit work can be avoided if the lighting distribution, like the power distribution, is run exposed except perhaps longitudinal branch circuit trunks, one on each side of the building, tied together at each riser, and to the riser tap box. Each trunk should pass through a "junction" outlet in each bay from which the branch circuit work in each bay, whatever it may be, originates. A standard system of inserts in each bay provides for every necessary arrangement of lighting. If the lighting is ever changed, the conduits and outlets may be taken off the ceiling and may be used elsewhere.

In Fig. 24 is shown a panel box set on, but separable from, a riser tap box. The feeder from one of the riser switchboards at the foot of the power risers described above, comes to a similar box on the first floor from the ceiling and then, as a riser, continues up to the sixth floor. The illustration shows a complete panel in its box but without trim or "dead front" feature installed. The main switch is of the quick break brush contact type. The branch circuit switches are a new toggle type.

Of course, if the most suitable location for any panel does not prove to be at a riser, it can be located anywhere else, and a tap from the riser extended to it, as shown in Fig. 15, page 288, where a standard panel has been placed in a stock room.

In more recent work the main switch is made a separate affair from the panel proper, and this is advocated as a general practice. Let the panel board, its busses, and its branches be one thing. Then, if a main switch, fused or unfused, fuses only, or special bus work is required or necessary, let them be an extension of the panel. In this way any special panels, if needed, can be built up of standard or semi-standard parts. Suppose only two, four, and eight branch panels are made, then by arranging the bus work at each end for strap extensions, and by drilling for reinforcing ten, twelve, fourteen, sixteen, twenty, twenty-four, etc.,

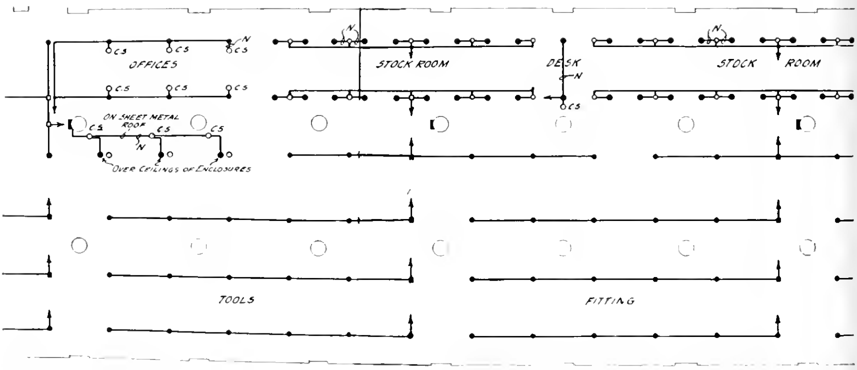


Fig. 25. Part of Circuit Routing, Fourth Floor

circuit panels can be built up at will, and the necessary main switches, remote control, fuses, tie busses, etc., added as desired. In the Bloomfield building ten circuit panels only were used, eight circuits for lighting, two for receptacle circuits, and two spare.

Receptacle Circuits

It was thought essential to install in this building an elaborate premanent insertion receptacle system, for possible tool lights, bench lights, soldering irons, drills, and the like. Originally it was intended to run these circuits in the columns and floor slabs, but the difficulty of working the conduits into the forms and reinforcing became insuperable and they were finally routed via the power main hangers in exposed conduits.

Of course, insertion receptacles are essential and they should be fairly numerous. But they are generally wanted on benches or tables—not on the columns, walls, or other predetermined locations. Probably a pair of permanent heavy insertion receptacles at each riser point will be enough for portable drills, vacuum cleaners, etc., and general maintenance work. Where such receptacles are wanted on assembly tables, etc., a small dead front safety-first knife switch has been mounted under the riser tap box controlling a receptacle main run in the under floor trench system to splice boxes, one on each column nearest a group of tables. From these splice boxes branches run to each table and feed the receptacles, through a fused dead front safety-first switch mounted under the table. Like the tool connections, all this work is in flexible conduit.

Illumination

There can be no question as to the advisability of using thoroughly good illumination in factories, and this applies quite as much to natural as to artificial light. No workman can be expected to produce a good, clean product if he cannot see his tools or has to strain his eyes in watching his work. There is too much convincing data covering this field in existence to leave it a subject for discussion. The cost of inefficiency due to poor lighting is large compared to the cost of luminious energy.

But given a reasonable amount of generated light we are brought face to face with the problem of how to distribute it so as to make it useful. On this phase of the subject reams have been written with the result that any practical conclusions are thoroughly concealed by a mass of theoretical camouflage.

In general the lighting of machine shops is simple because there is a broad similarity in the tools and kind of work done at them, so that generally speaking one or two kinds of fixtures will answer most requirements. It is essential that the vertical illumination or light intensity parallel to the floor be quite high—in fact almost equal to the horizontal illumination, or light intensity vertical to the floor. Furthermore, the light must come from several directions so as to prevent the occurrence of deep shadows, and to make the locating of tools so far as reasonably possible, independent of the lighting, because then changes in tool location do not necessarily mean expensive changes in the lighting system. If this can be done two things will be accomplished. First, the only changes necessary to accommodate the lighting to different kinds of machine work will be changes in intensity by changing the wattage at each outlet. Second, individual or local tool lighting will not be needed. The first cost and maintenance of such local lighting is high.

Special conditions will, of course, arise. Thus, polishing departments require almost entire absence of specular or metallic reflection from the work, as such reflection interferes with proper inspection. This requirement means that either the light on the work must come only from such directions that it cannot be reflected into the workman's eyes, or there must be no sources or surfaces of great brightness in the neighborhood, images of which can be reflected from the work. The first solution is accomplished by properly shaded and directed local lighting. The second solution may be accomplished by properly designed indirect or semi-indirect lighting with careful attention to brightness contrast and to diffusion This, of course, presupposes careful painting of the ceiling and walls which, with this method, become the real sources of light

Again, in the case of deep boring work, whereby the very nature of the machine process, the working surfaces are shaded in every direction, local lighting offers the only practical solution of the problem

It, therefore, seems that the most generally suitable and useful form of general machine shop lighting will consist of a broad general distribution of intensity coming from many directions, helped out by local lighting where essential or in cases where the general illumin-

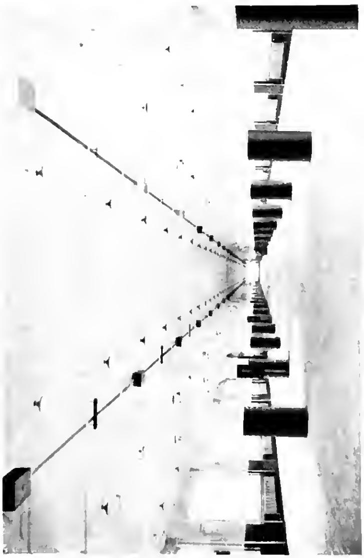


Fig. 28. Third Floor, Day Time

Fig. 29. Third Floor, Night

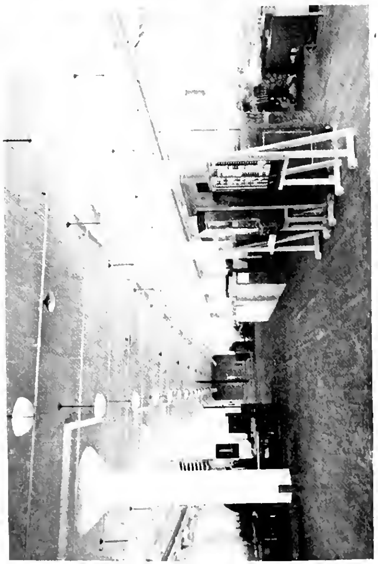


Fig. 30. Sixth Floor, Day Time

Fig. 31. Sixth Floor, Night

ation cannot be made sufficiently economically.

This result can be most cheaply accomplished in fairly low ceilinged rooms, say between fifteen and twenty foot ceiling height, by the use of a relatively large number of small units each giving the maximum amount of light between fifteen and sixty degrees from the horizontal. When we speak of a relatively large number of units remember that generally speaking every unit put on the ceiling means one less local unit. Also remember that generally speaking, each local unit costs considerably more than a ceiling unit.

Direct lighting units will be lower in the first cost than either indirect or semi-indirect units and remembering the difficulty of keeping factory ceiling and wall surfaces clean, decidedly less costly in energy consumed.

To obtain the results desired, and use the cheaper form of direct unit requires that the lamp be exposed. This however, will not be disturbing if the number of small units suggested are used. It results that the brightness is well distributed and the brightness contrast is not excessive. The lamps should be placed as near the ceiling as possible so as to have them out of general view when close at hand.

Lighting Fixtures

In the Bloomfield building, as has been shown in Fig. 6-B, the general illumination of manufacturing areas consisted of four units per bay. Two per bay being installed in packing, shipping, and storage areas.

Each unit consists of a simple Benjamin fitting attached directly to the outlet box equipped with an Ivanhoe-Regent SEL-100

Fig. 26. Standard Direct Lighting Unit

enameled steel dome reflector as shown in Fig. 26. Thus all wiring of fixtures and splicing in the outlet boxes are avoided. The fixture costs less than $2 erected. Each fixture is lamped with a 100-watt type C clear bulb lamp.

In the office spaces on the sixth floor semi-indirect lighting is used, employing four fixtures per bay of the type shown in Fig. 27. Each fixture is lamped with a 200-watt type C clear bulp lamp. Semi-indirect lighting is used in this case to reduce the

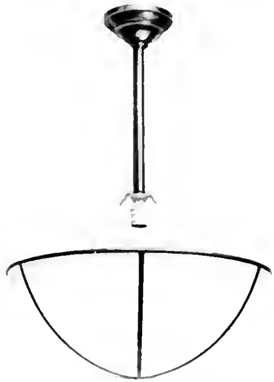


Fig. 27. Standard Semi-indirect Lighting Unit

contrasts to a point safe for close clerical work. The lighting of the stairways, fire lights, hose lights, etc., is economically and effectively accomplished by a simple one-light receptacle and lamp guard fastened direct to the outlet boxes.

A view of the third floor in the day time is shown in Fig. 28. The same view at night is given in Fig. 29. A view in the office portion of the sixth floor in the day time is shown in Fig. 30; a view in this floor at night is shown in Fig. 31. Note that the photographic plate shows little if any more halation about the fixtures on the third floor than on the sixth, indicating that the brightness even with the direct units was not excessive. Brightness measurements in candle-power per sq. in. are given in Figs. 29 and 31.

Attention is particularly drawn to these pictures of the illuminated interiors, as these, and not the test results, tell the real story.

Illumination Tests

And now a word as to illumination tests. Unfortunately, illumination is rated in horizontal intensity; that is in terms of the light flux received on an arbitrary horizontal surface called the "working plane"—why the "working" plane is not clear as hardly ever does any one work upon it. Better call it the "test plane."

As a matter of fact, the intensity in some direction other than the horizontal may be, and generally is, much the most important of the two. Thus, it is silly to rate the

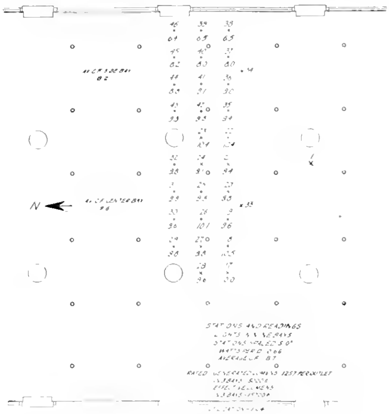


Fig. 32. Illumination Test, Third Floor

illumination in a can factory by the horizontal intensity near the floor, when it is intensity in precisely the reverse direction that is most helpful to the workman and enables him to see the dies on his press.

The results should be that the workman can see easily and readily what he is doing and that the place be cheerful and bright—a pleasant place in which to work. Otherwise the worker will not be happy and in some dictionaries unhappiness is spelled like inefficiency.

The shop must "look" right. And when I say that I have said all there is to lighting. Foot-candles, watts per sq. foot, lumens, lamberts, and utilization factors will not help us if the eye is not pleased. Of course, I do not mean to throw all these things aside. They will help in getting results. But do not let us get the cart before the horse. We do not see lumens—we see light, and light is primarily a visual sensation.

The results of the illumination tests made at the Bloomfield building are here given rather as a matter of formality—they mean nothing apart from the result that the shop is workable at night and during the dark hours of the day without a marked decline in production. This is foretold by the attitude of the workers and their general atmosphere of satisfaction. The same measurements of horizontal intensity over the test plane could have been obtained with an entirely different system of illumination that might not have produced anything like as satisfactory results.

The tests were made in a single section only—that is in the space three bays long, and three bays wide fed by a single riser, and panel. Furthermore, the tests on the third floor were made before the tools had been installed, it having been our intention to make a further test on the second floor where tools were in operation so as to show what effect the tools have on the illumination. Unfortunately, the coal shortage interfered and this test, as well as proposed ageing tests, will have to be reported later.

The results of the test on the third floor with all nine bays lighted are shown in Fig. 32. Two tests were made about a week apart. The repeat test was carried out because it was not believed that the results of the first test could be correct.

The first test was made by Messrs. Powell and Summers of the Edison Lamp Works using a freshly calibrated Macbeth illuminommeter. The second test was made by the same two men, together with the author, using a freshly calibrated Macbeth Illuminometer, a freshly calibrated Shape-Millar photometer and a second Sharp-Millar instrument that had not been used since last calibrated. Check readings, taken on all three instruments by three observers agreed within a candle foot. That is, within about 10 per cent. Voltmeter readings at the lamp terminals were also taken, and the readings corrected to correspond to the actual voltage at which the lamps were burned. The rated lamp voltage was 115 volts. The actual voltage during the test averaged a few tenths of a volt over this value.

Utilization Factor

It was, therefore, considered that every reasonable precaution to insure commercial accuracy had been taken. The results are interesting since with 0.66 watts per sq. ft. of floor area, an average illumination in the center three bays of 8.7 foot-candles was obtained 42 inches above the floor, and a utilization factor of 1.04—over a hundred per cent.

That is to say, more light is received on the test plane than is generated at the lamps.

This, however, is not by any means impossible. It is merely unusual, and is accounted for by the fact that the walls, floor, and ceiling show unusually high reflection factors. If the interior surfaces, except the floor, showed 100 per cent reflection factor and the reflection factor of the floor was 0.25 or 0.75 absorption factor—133 per cent of the light generated by the lamps would be received on the floor. Thus, if the lamp generates 100 units, all of this is initially received on the floor which reflects 25 per cent of what it receives, or 25 units. This is again reflected to the floor which again reflects 25 per cent of 25 units, or 8.25 units, and so on. If this be put in terms of per cent of the generated units we get a geometric series, that is,

Per cent light received on floor

$$
\begin{aligned}
&= 100 + 0.25 \times 100 + 0.25^2 \times 100 + \ldots \\
&= 100\,(1 + 0.25 + 0.25^2 + \ldots) \\
&= 100\left(\frac{1}{1 - 0.25}\right) \\
&= 133
\end{aligned}
$$

The utilization factor is merely the ratio of the light flux received on the test plane from all sources—ceiling and walls, as well as lamps—to the light flux generated by the lamps.

Similar tests were made in the sixth floor office space where semi-indirect illumination was used. With only four 200-watt standardized lamps burning in one bay, the average illumination on this floor was 6.87 foot candles, the utilization factor 0.34. With the lamps in all nine bays lighted the average illumination was 14.5 foot candles and the utilization factor, taking only the center bay into account, 0.75—a high but not impossible value.

Wall and Ceiling Treatment

The test results show the importance of properly treating all surfaces on which light flux may be incident, so as to reduce absorption to a minimum. Every lumen not absorbed on these surfaces means the need of one less generated lumen.

The readings shown of intensity on planes other than the horizontal are interesting as they indicate at once why local tool lights in this building are entirely unnecessary.

The efficiency of illumination in this building is undoubtedly high as it should be since every precaution was taken to obtain such results. The ceilings are painted with an impervious white semi-gloss enamel containing no lead and little oil—gums being substituted. This kind of paint shows a reflection factor of about 0.76 when fresh and painted on steel primed with red lead. The reflection factor falls off slowly with age, and the paint does not change color when applied to properly primed surfaces. Furthermore, the paint can be easily cleaned. The walls are similarly painted a light buff tone.

The windows are glazed with a rolled sharp angle ribbed glass, the glass being glazed with the ribbed side out. This results in diffusing the incoming daylight and reflecting back into the building a large part of the artificial light which otherwise would escape. The use of a glass with a larger 45 degree angle rib would have been still more effective.

This means that in computing illumination by the absorption method, the absorption by the windows so glazed is not a material factor in increasing the loss of light. In modern factories a large portion of the wall areas consists of windows.

Life in a Large Manufacturing Plant

PART VII. THE ELECTRICAL TESTING COURSE

By Chas. M. Ripley

Publication Bureau, General Electric Company

This chapter, which completes the educational section of the series, describes the training course which is open principally to graduates of technical colleges and universities. In the testing department these young men become familiar with the construction and operation of all forms of electrical apparatus, of a variety and magnitude that cannot be approached in college laboratories. The work that they perform is a necessary procedure in the manufacture of electrical apparatus and it should be definitely understood that this work is not specially devised for their instruction apart from regular production. It is this phase of the course that makes it of inestimable value to the student engineer, as he is required to handle the commercial product of the company in the stages between assembly and delivery. He therefore becomes familiar with the very latest types of apparatus, and in this way acquires experience that is denied to many men further advanced on their careers.—Editor.

There still exists the type of college man who fancies that the world is waiting with outstretched arms to receive him, and that his career in business will be merely coasting pleasantly down from the heights which he attained at college. Fortunately, in the engineering colleges especially, this type of man is being succeeded by men having a better outlook—men who have had practical experience during their summer vacations. They have few misconceptions regarding the magic power of the sheepskin to obtain for them a place in the world without hard work. On the contrary, more and more they are appreciating that what they learn with their sleeves rolled up is invaluable to their future success, whether they are destined to be engineers, executives, or sales managers. And there is no period of their life upon which they will look back with so much sentiment and gratitude as upon the days of practical work, when they learned among other things the democracy of overalls and a flannel shirt.

This chapter will describe the life of the college graduate who enters the General Electric Company's Test Course, and will trace the careers of almost 2200 of those who have completed the training.

The diagram on the opposite page shows that the General Electric Company's Test Course is an open door to the electrical industry; it suggests some of the activities for which the men will be especially trained; and it shows the various fields in which the college graduates will work out their own destinies.

It might be stated that, just as the temper of steel makes the tool hold its edge and just as the chemical of the photographer fixes the picture on the negative, just so does this practical training whet to a keen edge, fix, indelibly stamp on their memories and crystalize in their minds, the knowledge of electricity which they gained in their university training. Or to cite another parallel, it is similar to the medical student who, as an interne in a great metropolitan hospital, gets the practice which is necessary in order that he acquire the technique of his profession.

But before discussing this diagram and describing the careers of these young men, it would be well to suggest the magnitude of the future electrical industry and the increasing call for trained men to fill its responsible executive and engineering positions.

Electrification has Only Begun

Not over a tenth of the possible water power of this country has been developed; less than one per cent of the steam railroads have been electrified to date; five hundred miles of new track and one thousand new street cars are put in service annually; fifteen million houses are not lighted electrically; less than one per cent are wired for complete electric service. The electrical industry was practically born in 1879 when Thomas A. Edison invented the incandescent lamp, and was put on a commercial basis by Edison's three-wire system about 1882 — barely a generation ago! Twelve billion dollars is already invested in the electrical industry in this country. Last year $23 was spent per capita for electrical service and material. The annual gross income is over two and a half billion dollars. The employees number approximately one million. But the money to be spent in the next thirty-eight years and the size of the industry in 1956 stagger the imagination. The executives and the engineers who will direct the great electrification corporations of the next generation are in college today—many perhaps are reading this article.

Referring again to the diagram, attention is invited to the fact that the test course is indicated as a path between college and business. The average time required for the college man to traverse this pathway is fifteen months. His average earnings during this time at the Schenectady Works are $1277.15.

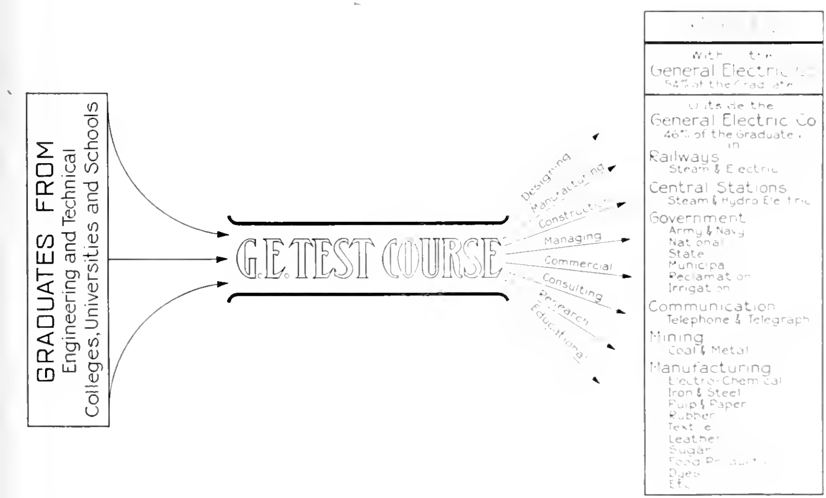
Foreign Fields

Before fully describing the Test Course let us review the electrical industry both inside and outside of the Company's organization, and find what positions are held today by the graduates of the Test Course in the past—at the same time bearing in mind that when we speak of the past in the electrical industry, we speak of an absurdly short space of time. The reader should appreciate that these young men are scattered over the four quarters of the globe, doing their share in the fascinating work of electrifying China, harnessing waterfalls in India, installing electrical drive in sugar mills in the West Indies, substituting electricity for steam or hand labor in the mines of Alaska and South Africa, building railways in Australia and refrigerating plants in the Philippine Islands.

CAREERS OF EX-TEST MEN

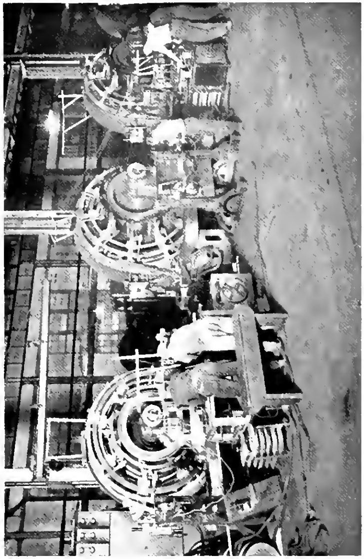
It is a difficult matter to make a survey of the careers of these young men. It was thought that perhaps the best method would be to ascertain how many of the old test men were members of the American Institute of Electrical Engineers. By checking one list against the other, it was found that the names of nearly 1000 graduates appeared on the membership list of the Institute, with present address, position, and title. Of this number about 350 hold positions with the General Electric Company and 122 are in foreign countries. One man remarked upon glancing over this list "This thoroughly proves that for the test man the world is his field and the sky is his limit."

It should be stated in connection with this list (Table V, page 311) that many engineers and executives of the Company are not members of the National body of the American Institute of Electrical Engineers.

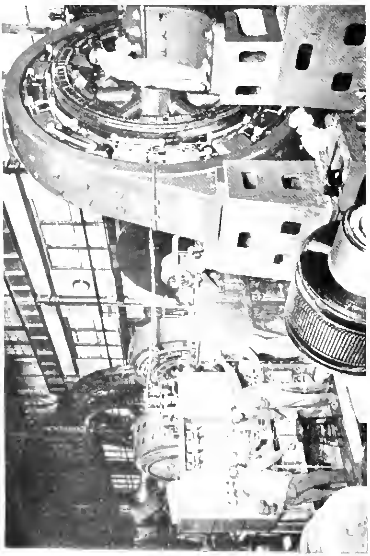


The Careers Open to Technical Graduates through the Test Course

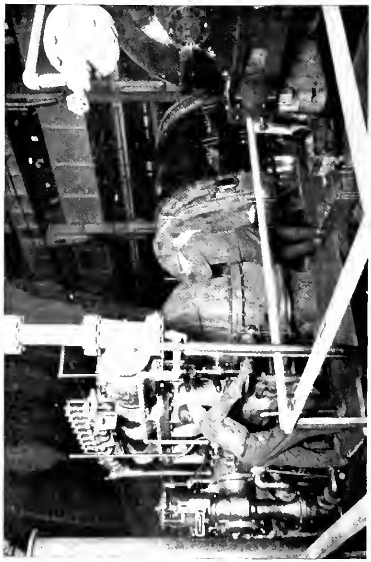
Motor Generator Test in Building No. 11 at Schenectady



Testing Large Synchronous Converters at Schenectady



Mine Hoist Equipment Under Test



Steam Turbine Test

but of local sections existing at Fort Wayne, Pittsfield, Lynn, Schenectady, Philadelphia, Chicago, Boston, and other cities throughout the country.

The field of activity includes: railways, central stations, governmental work, hydro-electrical development, signaling, army and navy, power transmission, electro-chemistry, manufacturing, and finance.

Mining, Steel and Railway Engineers

Many test men engaged in mining, railway work, and the iron and steel industry, etc., are members of related societies. For instance, the list of members of the Association of Iron and Steel Electrical Engineers shows that fourteen former test men are members of this Association, eight of whom are still with the Company. McGraw's 1917 list of railway officials (Table I) shows that the following positions are held by General Electric test men in the electric railway field:

TABLE I

ELECTRIC RAILWAY OFFICIALS FORMERLY GENERAL ELECTRIC TEST MEN

Presidents	12
Vice Presidents	27
Secretaries	15
Treasurers	18
Auditors	24
General Managers	18
Managers	12
Engineers and Superintendents	42
Inspectors	3
Master Mechanics	6
Purchasing Agents	3
Claim Agents	3
Land Commissioners	3
	186

Test Men in Engineering Departments

The extent to which test men are employed in the various factories and district offices of the Company is shown in Table VI, representing sixty-three General Electric engineering departments. This accounts for 577 ex-test men.

Since test men constitute 52 per cent of the engineering personnel, and probably 90 per cent of the technical force, more than one conclusion can be drawn:

1st. A large number of ex-test men are employed in the engineering departments of the General Electric Company.

2nd. For a college graduate the Test Course is the best if not the only route by which he can arrive at responsible positions in these engineering departments.

This census, dealing with sixty-three of the engineering departments, could be supplemented by another census dealing with one hundred and five or more commercial departments and sections of the Company in the above factories and in nearly one hundred cities throughout the world. This additional census has not been made, but a cursory survey apparently justifies the belief that the percentage of test men in the commercial work of the Company is even greater than in the engineering. And scores of student engineers enter the Construction, Administrative, and Manufacturing Departments, Laboratories, etc.

HIGH POSITIONS ATTAINED

Table VII shows the percentage of the Company's officers, managers, specialists, etc., who passed through the preliminary practical training in the shops "with their sleeves rolled up."

In addition, there are hundreds of engineers and business men, ex-test men, all over the country, not with the General Electric Company, who have branched off into the automobile business, who are proprietors and managers of power plants and various industries, officers in electrical jobbing concerns, etc. It would appear, therefore, that the young men develop versatility as a result of their theoretical and practical education.

COSMOPOLITANISM

The students who enter this course are practically a picked crew from the graduates of over one hundred engineering colleges in the United States—north, south, east, and west.

A total of 257 students have been accepted from colleges in over twenty-two foreign countries. These foreign graduates can be grouped as follows:

TABLE II

	Students
China	38
South American Countries	34
England	30
Japan	29
India	18
Australia	17
South Africa	17
Canada	10
West Indies	10
France	6
Other countries	48
Total	257

Therefore it may be said without exaggeration that the test men are a cosmopolitan, highly educated group of young men.

College Professors and Instructors

The instructive value of the Test Course is indicated by the fact that instructors and professors from many technical colleges have found it of advantage to spend their summer vacations in the Testing Department of the Company, in order to keep in touch with practical manufacturing methods and to learn more of the design and operating characteristics of the latest electrical machinery and appliances. A number served in test regularly after graduation.

Magnitude of the Testing Department

The Testing Department of the General Electric Company occupies 732,486 sq. ft. of space. This area in down-town New York would cover nearly fifteen city blocks, each the size of that occupied by the Equitable Building, which is bounded by Broadway, Nassau, Cedar, and Pine Streets. It is 29 per cent greater than the entire rentable area of the Woolworth Bldg. Or in Chicago, this space is 238 per cent as large as the entire rentable area of the Railway Exchange Building on Michigan Avenue and Jackson Boulevard.

This space is distributed among the different factories as follows:

TABLE IV

	Sq. ft.
Schenectady	428,458
Pittsfield	64,000
Fort Wayne	47,070
Lynn	131,958
Erie	50,000
Sprague	11,000
Total	732,486

TABLE III

KV-A. CAPACITY OF APPARATUS USED IN TESTING

	Motors	Generators	Transformers	Total Kv-a.	Power Supply
Schenectady	32,000	78,000	30,000	140,000	37,000
Ft. Wayne	3,163	1,535	2,552	7,250	4,325
Erie	5,117	3,595	4,943	13,655	9,000
Lynn	3,684	4,724	4,955	13,363	12,000
Sprague	1,500	300	200	2,000	
Pittsfeld	12,000	30,000	29,000	71,000	7,200
Total	57,464	118,154	71,650	**247,268**	69,525

THE TESTING DEPARTMENT

The Testing Department is as distinctly a department of the Company as is the Production, Purchasing, or any other; and its work must be conducted on a strictly manufacturing basis—time and cost records being kept and compared with existing standards.

The great outstanding difference between the Testing Department and other departments is that it occupies space in a great many different buildings and deals with an enormous variety of apparatus. Hence it is ideal for developing a knowledge of the Company's products. In Schenectady, for instance, the Testing Department has permanent headquarters in fourteen different locations distributed throughout the Works. The reason for this scattering is that the apparatus is tested where it is manufactured. In a typical building the rough castings are received at one end, where they are machined; they are assembled at about the middle of the building and, after being tested, are painted near the far end of the building and are boxed and loaded on railroad cars inside the extreme end of the same building. It is thus seen that the men in the Testing Department are under the same roof where complete manufacturing processes are conducted.

Enormous Capacity of Testing Apparatus

Would you believe it possible that the General Electric Company should set aside and reserve merely for testing purposes electrical apparatus totaling almost 250,000 kv-a.? This statement is, however, a conservative figure, since it does not include the power stations—a certain portion of which is used for testing purposes. The capacity of this apparatus is half as great as all of the power generating apparatus at Niagara Falls.

Table III shows the capacity of apparatus used for testing.

Machines Help to Test Each Other

Inspection of Table III brings out some very interesting facts. For instance, at

Pittsfield the power station has only one-tenth the capacity of the Testing Department! The total capacity of apparatus reserved for testing in each factory is greater than the capacity of its power supply. This situation is largely due to the "feeding back" method, by which two motors, both under test, are used for testing each other—one running as a generator and the other as a motor, thus saving floor space, power, and generating capacity. By this last "feeding back" method, testing can be done on an enormous scale with the use of a comparatively trifling amount of coal, as the machines being tested supply most of the electricity required for testing them, only the losses being supplied from the power station.

Operating Knowledge

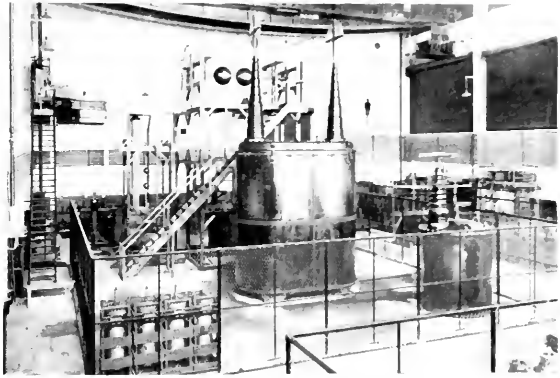
What may be considered as a by-product of the knowledge gained in the Testing Course at the Schenectady, Lynn, and Fort Wayne Works is the fact that there are no operators to take charge of this huge aggregation of electrical testing apparatus, because the student engineers themselves operate the machines which are used for testing the Company's product. With this operating experience, a graduate of the Test Course can enter almost any main station, sub-station, or switchhouse and take charge of its electrical operation.

The efficiency of modern electrical protective devices is well demonstrated here, for all this apparatus runs year after year under varying conditions, in charge of a shifting crew of student engineers (excepting the Pittsfield room shown in the photograph on page 305).

Wide Variety of Work

The fact is not as generally understood as it should be, that the student engineers are continually shifted from one kind of work to another, and are consulted regarding the sort of work they desire to specialize in and also what class of testing they desire to take up month after month.

For example, if a student engineer has expressed a preference for turbine work, he can spend fifty per cent or more of his time testing large and small turbo-generator sets. Turbines are tested non-condensing and with vacua up to 29 inches, and the student becomes familiar with the properties of steam ranging from 200 degrees superheat down to 20 per cent moisture.



High-voltage Testing Equipment at Pittsfield

Steam Engineering

Turbines for the latest power plants operate with steam at 250 degrees superheat and 29 inches vacuum on the exhaust. The students gain a working familiarity with boiler steam that is hot enough to melt tin and get a knowledge of the types of piping, fittings, gaskets, valves, etc., required to resist such temperatures.

Among the variations in turbine testing are the ship propulsion units being manufactured. Some of these are being fitted with the Alquist flexible reduction gears, while others employ direct electric drive—both developments of the Company.

In connection with the testing of generating apparatus, attention is directed to the photographs of turbine and marine steam engine testing, which show a great amount of high pressure and low pressure piping to turbines, engines, condensers, pumps, etc. One of the surprises in store for the student engineer who enters this course is the vast amount of information which he secures in regard to steam. With the central stations calling for higher and still higher efficiencies, the General Electric Company has co-operated with the boiler industry on the one hand and the condenser industry on the other to produce higher pressures and higher superheat from the one, higher vacua from the other, and greater capacity from both.

The student engineer lives in an atmosphere of practical thermodynamics while he is in contact with turbine and marine engine tests. An indication of the scale on which this mechanical-electrical phase of the Company's testing has been developed is shown by the fact that recently a condenser equipment was placed in Building 60 at an expense of $300,000, and a steam equipment is being installed in Building 49 at a further expense of $200,000—both solely for testing purposes. Such is practical turbine testing today In comparison with this work the little jet and barometric condensers in the old college "lab" are but cunning toys.

An idea of the variety of apparatus operated and tested by these young men is given by the following schedule:

APPARATUS TESTED BY STUDENT ENGINEERS

(Schenectady Course)

Building 11—Motor generator sets up to 500 kw., synchronous converters, planer panel equipment, lighting generators, government motors, developmental work.

Building 12—Railway motors, mill, mine and crane motors.

Building 18—Induction motors up to 150 h.p., d-c. motors and generators, motor-generators up to 300 kw.

Building 60—Steam turbine a-c. and d-c. generating sets, ship propulsion turbines for gear and electric drive.

Building 40—Induction motor starting compensators.

Building 52—Industrial control devices, field and starting rheostats, control panels, industrial appliances.

Building 16—Motor generators above 500 kw., synchronous converters 500 kw., frequency changers 500 kw., large water wheel generators, synchronous motors, steel mill equipment, fly wheel sets, double speed tests.

Building 52—Induction motors above 150 h.p., speed regulating sets variable speed a-c. motors.

Building 60—Train control panels, mill and mine hoist panels, controllers—all kinds, contactors and insulators.

Building 61—Efficiency tests on turbines, steam flow meters, special tests on large apparatus from other buildings.

Building 32—Voltage regulators, contact making voltmeters.

Building 28—High voltage tests up to 750,000 volts.

Test Track and Building No. 203—Railway developmental work.

At Pittsfield—Power transformers, feeder regulators, a-c. motors.

Power Equipment for Testing Transformers at Pittsfield

First to Operate Big Installations

This wide variety of apparatus illustrates the breadth and scope of the test man's work; for it embraces the latest, and hence the most interesting, electrical and mechanical devices manufactured. When the engineer of a Chicago, Milwaukee and St. Paul electric locomotive throws his controller handle one notch ahead, he but duplicates what an electrical test man had previously done When an operator of the great locks of the Panama Canal throws the switches which permit a 32,000-ton battleship to pass through, he also merely operates what the student engineer had previously tested and adjusted. And in the great steel mills, central stations, mines, and battleships, and in the thousand and one other places where electricity is used, every piece of electrical apparatus has been tested previously by student engineers. This follows from the fact that no machine can be shipped unless O. K'd by the Testing Department.

What Are the Facts?

The student engineers are not told what specifications and efficiencies the machines are guaranteed to fulfill; they are instructed as to what standard and special tests should be made. Thus they make all the electrical preparations, observations, and measurements, calculate efficiencies and plot curves of performance, all of which are checked and compared with the guarantees by those who are responsible for the decision as to when a machine is ready to be shipped.

Responsibility

In all of this shop work the student engineers are temporarily a part of the well-organized testing department, and they become personally responsible for the conduct of the tests of which they have charge. No matter in which of the above buildings they are working, they are under the direction of the seventy-five men of the permanent testing department. These men show the student engineers how to make rapid diagnoses of unexpected performance by any kind of apparatus or device. This suggests to the inquiring mind that the test man becomes an expert "trouble shooter," and that wherever he may encounter electrical machinery of any kind, he will probably be fully capable of adjusting the connections, controllers, brushes, poles, armatures, bearings, or foundations, or to otherwise diagnose trouble, restore the machinery to full operation, and instruct the operator how to obtain continuous satisfactory performance.

As not over 10 per cent of the electrical and steam installations sold by the General Electric Company are erected by the Company's construction department, it is apparent that the remaining 90 per cent, when shipped, must be ready to operate. Thus the customer's engineers or electricians set the apparatus on the foundation according to drawings and instructions of the Company, make the wiring connections according to the diagram furnished with the machinery, and expect the new installation to start up and operate without a hitch when the switch is thrown. If the test men have done their duty properly, there will be no trouble when the customer follows directions. Since the cost of satisfying customers' complaints has been reduced to a negligible per cent of the cost of the apparatus, it would appear that the test men had thoroughly mastered the details and intricacies of the electricial machinery and controlling devices, and properly adjusted everything—even to the smallest relay.

Government Work

As to the broad knowledge of the test men, let us consider only one phase of the testing work of today—government work. Seventy-five hundred horse power motors are being built to propel some of our latest battleships; as are also the turbo-generators which supply electricity to these motors; the Curtis turbines which will propel so many of our new emergency fleet; the gears which will transmit the power from these turbines to the propeller shaft; the motors which rotate the turrets of battleships and hoist the ammunition; the generators for the wireless; and the small marine steam engine-driven lighting units. All of this apparatus, whether of 30,000 kv-a. or $2\frac{1}{2}$ kw. capacity, is tested, adjusted, and studied by the student engineers before it is shipped.

To maintain perfect operation of these machines so vitally necessary to modern warfare, who would be so well fitted as the man who originally tested them or identical machines? The Army and Navy Departments in selecting officers to take charge of the electrical equipment of our great war vessels were quick to grasp the opportunity of engaging test men as chief electricians, chief engineers, wireless operators, etc. Can you imagine the delight in the heart of a young naval officer when he goes to his post of duty on a battleship, cruiser, destroyer, or submarine and finds there some machines which he himself had tested and adjusted in the old days at Schenectady or Lynn! He understands their language. They respond to his touch and will faithfully perform their heroic tasks in partnership with him.

Government Recognition

That the United States Government recognizes the value of practical testing work has been demonstrated in at least two ways.

In 1917, in the midst of their test course, 252 student engineers left to enter military service. Of the 150 who left Schenectady, 90 per cent have already received commissions; as have ten out of thirteen who left Fort Wayne—some holding offices in the army, as high as major or captain, and in the navy, such rank as ensign, lieutenant, chief electrician, etc., all in less than one year!

Among the hundreds who went to war, only those who left during the Test Course have been included in this survey.

Civil Service Requirements

But government recognition is not limited to military matters. The United States Civil Service Commission's printed form No. 2204, issued in 1917, in speaking of educational training and experience which applicants must have for Civil Service positions, mentions:

> "and at least one year's additional experience in testing electrical machinery."

Civil Service Form No. 1785, issued in 1917, especially mentions among the necessary qualifications of experience and training:

> "one year's experience in the testing of electrical machinery and apparatus."
>
> "five years experience in inspection and testing of electrical machinery and apparatus, two years of which must have been work on the test floor of an electrical manufacturing company."
>
> "three years engineering experience in installation or manufacture of electrical machinery, one year of which must have been inspection or testing."

CLASSROOM INSTRUCTION

Lectures

The theoretical phase of the training is taken care of by an extensive series of lectures which are given to the student engineers by prominent designing, research, and production engineers, and commercial managers of the Company. Not only are these lectures free, but the students are paid full time while attending them. Attendance is not compulsory and the student may attend one or two each week as desired. These lectures are given between 4:30 and 5:30 p.m., after the close of the working day. In order to render them as valuable as possible and to afford opportunity for the asking and answering of questions, the engineers give each lecture several times so that the attendance at each class can be kept small and the lectures entirely informal. This has an added advantage in that those students who have missed a lecture may be able to make it up later.

Preventing "Over Specialization"

The purpose of these lectures is to round out the student's knowledge of the Company's product as well as develop his versatility. The young men are encouraged in their desire to become specialists, but are prevented from becoming narrow-minded by the broad fields of knowledge that are opened up to them by these various lectures. For example, if a student engineer desires to become a commercial man, these lectures give him information of a technical character which will make him a better commercial man; if he desires to become a designing engineer, they give him a knowledge of many of the Company's commercial methods; should he believe that his future career will lie entirely along operating and managing lines, he will derive a knowledge of cost accounting, production, welfare work, research developments, safety campaigns, factory methods, tookmaking, industrial education, etc. Altogether there are fifty lectures at Schenectady, twenty-five at Pittsfield, twenty at Lynn, and seventeen at Ft. Wayne.

Bearing in mind the varied careers of the ex-test men, it will be seen from the number of presidents, general managers, executives, consulting engineers, directors, superintendents, commercial engineers, etc., that there is great demand for versatile men with a wide field of knowledge, as well as an intensive knowledge of one kind of work or apparatus. It is the old question of which is better:

To know something about everything, or
To know everything about something.

Attentive attendance at these lectures will help the young men to know something about everything electrical, and will also indicate the way and the individuals through whom they can learn everything about something.

Students may attend each of these lectures more than once if they desire.

Post Graduate Course at Union College

Student engineers who have completed a four-year college course or equivalent, with B.S. degree, and who wish to continue their electrical education from the theoretical standpoint, can obtain their advanced Master's degree at Union College. The Company refunds over 50 per cent of the matriculation and tuition fees to those who have secured their degree. The classes are held every Friday morning on the Company's time, thus making the student engineers' working week practically five days only.

This post graduate work is a two-year course and is a comparatively new development, inasmuch as it was organized in 1916. There are now thirty-five students enrolled, ten of whom, it is expected, will be graduated in 1918 with the degree of Master of Science.

The post graduate course consists largely of lectures and demonstrations, although numerous problems are given for home work.

Curriculum

I. *Advanced Electricity, by Prof. E. J. Berg.*
II. *Mathematics of Electrical Theory, by Prof. Vedder.*
III. *Lectures on Electron Theory; Electrical Properties of Gases and Liquids, by Prof. Kleeman.*

Lynn—M. I. T.

A co-operative course between the General Electric Company and the Massachusetts Institute of Technology is described on pages 102–105 of the Institute's latest catalogue.

ADVANCEMENT

The college men enrolled in the test course, it might be correctly stated, are a floating population—they are in a continuous state of flux. A few weeks after their arrival, they begin their migrations, emigrating from one department and immigrating into another.

Transfers

Every week from twenty to forty men are transferred to a new kind of work. There is no stagnation, no routine, no winding of armatures and field coils, very little if any repetition of any kind of work beyond the point where it ceases to be interesting to the average man. As long as a young man with an active mind is doing something different from what he did last week, or better than he did it yesterday, his knowledge is broadened. Six months passes more rapidly in this fascinating work than six weeks does in the dull details of routine. Every student who stays in the course is transferred. If he can keep up with the procession, he moves along; if he cannot keep up with it, it is suggested that he is probably better fitted for other lines of work.

At regular intervals the student is given a blank entitled "Application for Transfer" in which he indicates a preference for the line of work which he is to undertake next.

Thus the student engineer is directing and designing his career by selecting the several different tests which he desires to undertake. This brings up the fact that there is no set curriculum, *all* of which he must follow, but that among the fourteen classes of apparatus to be tested he can have his choice, as far as production conditions permit.

The student engineer makes out several of these applications for transfer during the time spent in the test course and, at the bottom of each, the head of the section where he has been working grades him according to the following qualifications:

Technical ability
Industry
Neatness
Accuracy
Ability to push things
Personality

These gradings are then posted upon a card, so it can be seen at a glance whether he is excellent, good, fair, or poor in any or all of the six qualifications. These cards are available for each man's inspection, but otherwise are confidential. Good marks in regard to personality are especially necessary for those desiring commercial work in the future.

At the end of six months other events take place which will affect his future career. Every student receives a letter from the Superintendent of the Testing Department as follows:

"Positions in the various departments of the Company are continually opening up, and in order to fill these most satisfactorily it is necessary to know the nature of employment each man desires, and feels he is best fitted for.

"With this idea in view, and to cause each man to consider well the line of work he wants, this note is being sent to men who have been on test six months.

"No man will be recommended for employment until he has filled out the attached slip and turned it in to the test office in person."

Thus again the individual's personal choice and ambitions, together with such business relations as he may have established before entering the test course, are taken into consideration before he expresses a preference as to his future work.

Office Training

After six months or more have elapsed since the college man entered the test course, another variation presents itself to those who have made a good record. The Superintendent of the Testing Department selects men for a three months' assignment to the various offices in the engineering and commercial departments, at the end of which training they return to the Testing Department. This sample of what designing and commercial engineering work really is, is afforded so that they may more fully appreciate the value of the testing work, and also that they will be better able to decide on the kind of work for which they are adapted—and possibly revise their choice as shown on their preference blank.

Promotion

Promotion from the Testing Department is not haphazard; it is not for the star members only; it is universal. For, as stated above, those who remain in the test course will be promoted, and those who will not be promoted do not complete the test course. Every week approximately seven men complete the test—four being promoted and three leaving for positions for which they have been recommended, outside the Company.

Trial Period

The first step in the promotion of a man is the "trial period" of three months in the department where permanent employment is anticipated.

By this means the department heads will have the privilege of trying out a man in order to be certain that his personal qualifications and temperament are suited for the position. This is just as important to the test man as it is to the department head and to the whole organization; and right here in this policy will be found one of the secrets of the success of the General Electric Company: Every man is peculiarly fitted by practical experience for the work which he does.

The Testing Gang at Lynn in the Old Days

Value of Practical Experience

Hundreds of examples could be cited to prove that the unromantic work of repairing engines and generators and even inspecting boilers is a valuable asset to an engineering career in the electrical industry. For instance Mr. W. B. Potter, Engineer of the Railway and Traction Engineering Department, took a position in the Testing Department at the Lynn Works in 1887 and has preserved the original letters leading up to his engagement. These form an interesting parallel to later correspondence in which he stated:

> "My shop experience and the knowledge of electric and steam practice has continually proved of inestimable value."

And Mr. E. E. Boyer, who holds a high executive position in the Lynn Works, entered the Testing Department there in 1885. The following paragraph is abstracted from a letter written to him by the superintendent, April 17, 1885:

> "Our requirements are that each applicant must serve a certain period in the workshop building the different parts of our apparatus, then serve awhile in the assembling room, and finally in the testing room, the time occupied being from four to six months. The pay during this period is but sufficient to provide for your board, and would be $1 per day."
>
> (Signed) E. W. Rice, Jr.
> *Superintendent.*

This discloses the fact that the idea of building an organization on the foundation of practical training was put into effect thirty-three years ago by the superintendent, now President of the Company.

Building An Organization

Mr. Thomas A. Edison says:

> "Problems in human engineering will receive during the coming years the same genius and attention which the nineteenth century gave to the more material forms of engineering."

The great idea of human engineering, with which is associated vocational training and wisely managed employment departments, is a product of the twentieth century; and yet the letter signed by the superintendent in 1885 would indicate that there were some individuals living in the nineteenth century who fully appreciated this point in forming the nucleus of a business staff now second to none.

Additional Information

In the 32-page booklet (Y-975) entitled "Practical Training for Engineering Graduates," the social opportunities of the student engineers are outlined, and photographs included showing exterior and interior views of the Edison Club, Edison Hall, and the Boat Club in Schenectady; also the Thomson Club at Lynn, and aquatic sports at Pittsfield and Schenectady. Other information is given regarding athletics, home life, cost of room and board within walking distance of the Works, climate, topography of the country, and size of the various Works of the Company.

TABLE V

POSITIONS NOW HELD BY EX-TEST MEN AS ASCERTAINED FROM NATIONAL MEMBERSHIP LIST OF A.I.E.E.

	In G-E Company	In other Companies
Abroad in Business	15	107
General Officers		
Presidents	1	10
Vice Presidents and Assistants	1	15
Secretaries and Assistants	..	6
Treasurers	..	3
Managers		
General Sales	2	..
Advertising	1	..
General	..	25
Assistant General	..	4
Works	3	..
District	2	6
Assistant District Department	2	..
Local	10	2
Department Sales	7	..
Directing	1	1
Department	14	2
Contract	1	1
Business	..	1
Employment	1	1
Assistants	3	2
No designation	..	16
Superintendents		
General	..	7
Of Motive Power	..	3
Division or District	..	2
Assistant General	..	2
Assistant Electrical	2	..
Assistant	2	4
Welfare and Assistant	2	..
Technical	1	..
Construction	1	2
Meter	..	1
Mechanical	..	2
Commercial	..	3
Electrical	2	6
Not designated	..	18
Electrical Engineers	251	338
Miscellaneous	33	218

TABLE VI

PERCENTAGE OF TESTMEN IN ENGINEERING DEPARTMENTS

Schenectady

Departments	*Per cent*
A-C. Engineering	70
Construction	37
Construction Engineering	20
D-C. Engineering	95
D-C. Motor Engineering	80
Flow Meter	57
Induction Motor	70
Industrial Control	70
Industrial Heating Device	75
Insulation Engineering	29
Lighting	95
Power and Mining	89
Publication Bureau	24
Purchasing	0
Railway and Traction	83
Railway Equipment	71
Railway Locomotive	50
Railway Motor	69
Regulator	66
Research Laboratory	40
Searchlight	20
Standardizing Laboratory	40
Switchboard	41
Testing Laboratory	25
Turbine	63
Wiring Supplies	50

Testmen in above 26 departments average 51 per cent

Lynn

Automobile Motors	75
Fabroil Gear and Pinion	33
Gear and Pinion	100
Meter and Instrument	18
Motor	75
Rectifier Tube	75
Street Lighting	55
Transformer	80
Turbine	57
Wire and Insulation	67

Testmen in above 10 departments average 63.5 per cent

Pittsfield

Lightning Arrester	91
Motor	33
Transformer	83

Testmen in above 3 departments average 69 per cent

Fort Wayne

A-C. and D-C. Apparatus	57
Automobile Accessories	50
Fractional H.P. Motor	58
Meter	20
Rock Drill	0
Transformer	78

Testmen in above 6 departments average 44 per cent

Sprague

Conduit Products	0
Hoist	33
Motor and Generator	33
Ozonator	100
Switchboard and Panelboard	0

Testmen in above 5 departments average 33 per cent

Erie

Air Brake	17
Gas Engine	20
Power and Mining Loco	43

Testmen in above 3 departments average 27 per cent

District Offices	
Atlanta	60
Boston	64
Chicago	75
Cincinnati	50
Dallas	0
Denver	67
New York	77
Pacific Coast	50
Philadelphia	50
St. Louis	47

Testmen in above District Engineering Offices average.................54 per cent

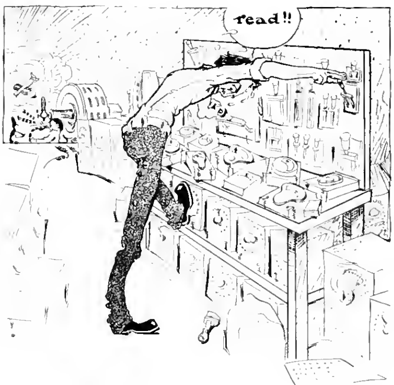
AVERAGE in above 63 departments, 52 per cent

TABLE VII

PERCENTAGE OF GENERAL ELECTRIC OFFICIALS, MANAGERS, SPECIALISTS, ETC., WHO ARE EX-TEST MEN

	Percentage
Power and Mining Eng. Dept. Section Heads	100
Local Supply Dept. Mgrs.	100
District Power and Mining Dept. Mgrs.	100
District Lighting Dept. Mgrs.	100
Transformer Specialists	92
Switchboard Specialists	89
General Office Commercial Dept. Ass't Mgrs.	83
Local Small Motors Dept. Mgrs.	83
District Engineers	80
Schenectady Designing Engineers	78
Local Engineers	75
Resident Agents	74
General Office Dept. Mgrs.	73
Local Managers	72
General Office Commercial Dept.	71
Local Apparatus Dept. Mgrs.	67
Meter Specialists	64
General Office Supply Dept. Section Heads	63
Schenectady Designing Engineers (Supplementary)	62
District Railway Dept. Mgrs.	60
Foreign Sales Offices	56
District Small Motors Dept. Mgrs.	50
District Apparatus Dept. Mgrs.	43
District Supply Dept. Mgrs.	43
Heads of Laboratories	43
Works Managers	40
District Managers	40
General Office Commercial Dept. Mgrs.	39
General Office Administrative Dept. Mgr. (Supplementary)	33
Heating Device Specialists	31
Railway Supply Section Heads	30
Local Chief Clerks	27
District Fort Wayne Dept. Mgrs.	25
General Office Administrative Dept. Mgr.	20
District Order Dept. Mgrs. and Clerks	20
General Officers	20
Production Managers	17
Domestic Device Specialists	6
General Office Accounting Dept. Section Heads	0
Works Accounting Dept.	0
Local Auditors	0
District Auditors	0

Among 42 lists of officers, etc., average per cent of ex-test men.........51 per cent



"Taking Speed Curve"

P.T.M. discovers that his plugging from board B. is OK.

TWO DOLLARS PER YEAR TWENTY CENTS PER COPY

GENERAL ELECTRIC REVIEW

VOL. XXI, No. 5

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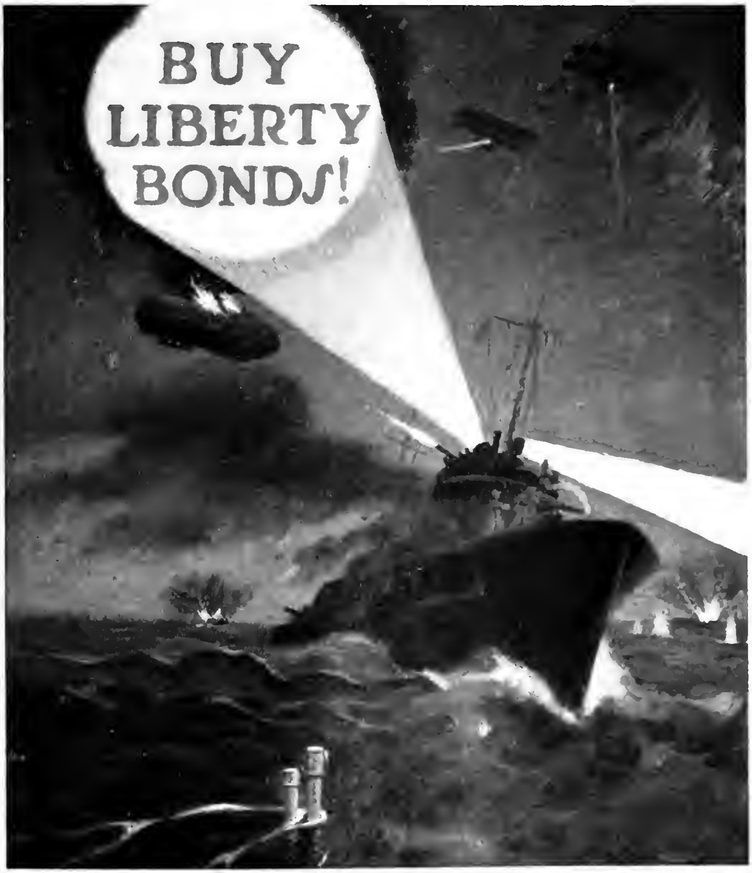

General Electric Review

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE — Editor, JOHN R. HEWETT — Associate Editor, B. M. EOFF — Assistant Editor, E. C. SANDERS

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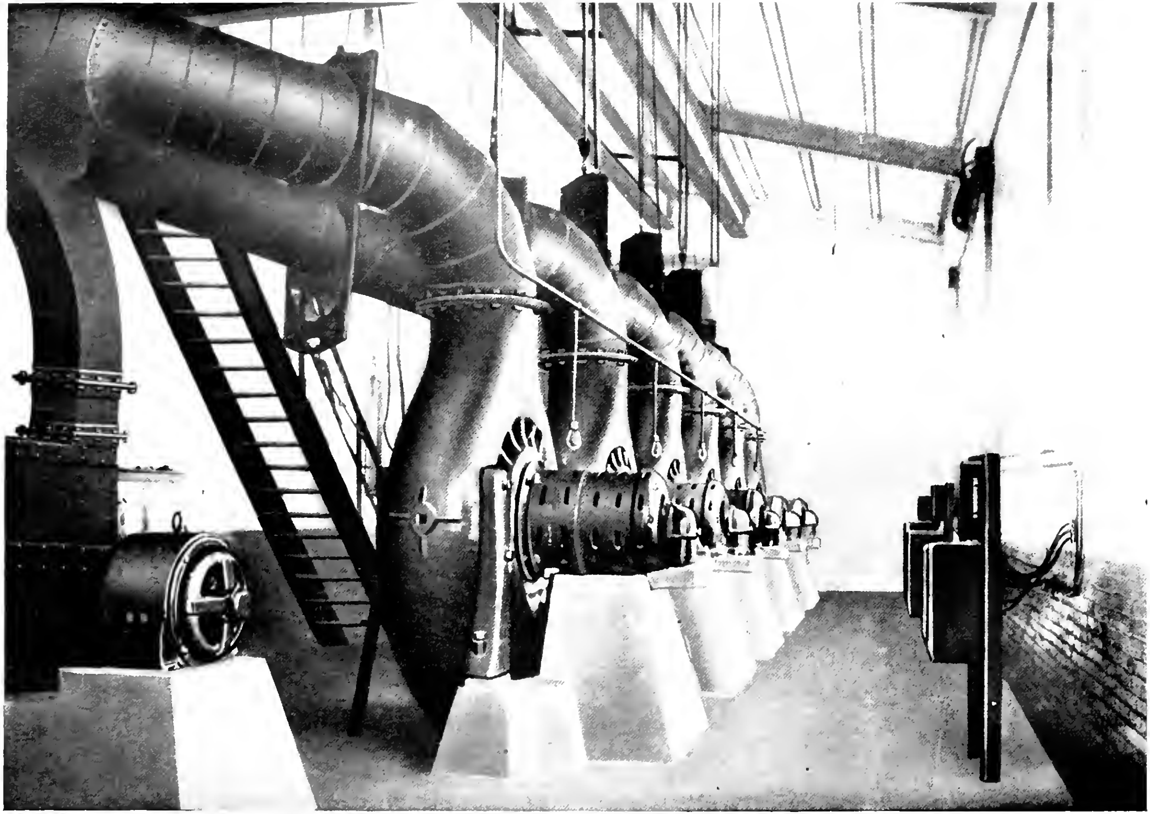


Seven Centrifugal Air Compressors Installed at the Washoe Smelter of the Anaconda Copper Mining Company, Anaconda, Montana. These machines are of 10,200 cubic feet capacity each, and furnish air for blowing pulverized coal into reverberatory copper smelting furnaces. The seven units deliver over 70,000 cubic feet of air per minute at a pressure of 1 lb. per sq. in., which is sufficient to draw in additional air by induction. This plant is at an altitude of 5000 feet, and is the largest pulverized coal installation in existence. Six more compressors of the same capacity are to be installed at the new smelting plant of the United Verde Copper Company at Clarkdale, Arizona. See article, page 373, Methods for More Efficiently Utilizing Our Fuel Resources.

GENERAL ELECTRIC REVIEW

MOTOR POWER FOR "THE HEART OF THE WORLD"

Last June you were asked to contribute to the First Red Cross War Fund; and you gave more than a hundred million dollars. Last December you were asked to become members of the Red Cross; and seventeen million of you did, bringing the total enrollment to twenty-two million. These responses indicate the faith you had in that organization.

Now, the Red Cross announces that its service during the past year to our Country and her Allies has necessitated appropriations that have about exhausted the First War Fund. To provide the money necessary to continue the humanitarian work during the coming year, the President of the United States (also President of the Red Cross) has appointed the week of May 20–27 as the period during which an intensive appeal will be made to you to contribute to a Second Red Cross War Fund of one hundred million dollars.

In advance of making this second appeal to you for an operating fund, the Red Cross has prepared a report of its past performance to substantiate the faith you have placed in its ability to spend your money wisely. Copies will be obtainable from the Chairman of the Local Red Cross Chapters.

For the information of those who analyze expenditures, the report includes the following financial statement:

First War Fund Appropriations up to March 1, 1918

Foreign Relief:	
France	$30,936,103.04
Belgium	2,086,131.00
Russia	1,243,845.07
Roumania	2,676,368.76
Italy	3,588,826.00
Serbia	875,180.76
Great Britain	1,885,750.75
Other Countries	3,576,300.00
Relief for prisoners, etc.	343,304.00
Equipment and expenses in U.S. of Personnel for Europe	113,800.00
Total Foreign Relief	$47,325,609.38
Restricted as to use by Donor	2,520,409.57
United States Relief:	
Army Base Hospitals	$54,000.00
Navy Base Hospitals	32,000.00
Medical and Hospital Work	531,000.00
Sanitary Service	403,000.00
Camp Service	6,451,150.86
Miscellaneous	1,118,748.41
Total U.S. Relief	$8,589,899.27
Working capital for purchase of supplies for resale to Chapters or for shipment abroad	15,000,000.00
Working cash advances for France and United States	4,286,000.00
Total of War Fund Appropriations	$77,721,918.22

The inclusion of such a dollars-and-cents statement is a commendable procedure that could well be adopted by other institutions which solicit contributions to their maintenance, for it is indicative of the business-like character of the management. The amounts of the individual items ably show the immensity of the Red Cross's activity in monetary units. Surely there could be no stronger financial argument than this to convince you that you should give liberally to the establishment of a Second Red Cross War Fund for the continuance of the relief work during the coming year.

Since the work of the organization covers almost every kind of humanitarian relief that money and effort can bring about, it would be practically impossible to list all its activities in this war upon Military Autocracy.

However, even the mention of some of them will serve to demonstrate that the scale of their magnitude and variety is of the same order as the destructive effects of the War's military activities which they endeavor to remedy.

The Red Cross established infirmaries and rest stations along all routes followed by the American troops in France.

It built canteens for the use of American and French soldiers at the French Front, also at railroad junctions, and in Paris.

It supplied American troops with comfort kits.

It organized and trained 45 ambulance companies, totaling 5580 men, for service with American soldiers and sailors.

It built and maintained four laboratory cars for emergency use in stamping out epidemics at American cantonments and training camps.

It supplied 2,000,000 sweaters to American soldiers and sailors.

It mobilized 14,000 trained nurses for the care of our men.

It made arrangements to supply American prisoners in Germany with the same rations as given to the men in the trenches.

It established a hospital distributing service that supplies 3423 French military hospitals and a surgical dressing service that supplies 2000.

It provided an artificial limb factory and special plants for the manufacture of splints.

It opened a children's refuge hospital in the war zone and established a medical center and traveling dispensary to accommodate 1200 children in the reconquered sections of France. Fifty thousand children throughout France are being cared for in some measure by the Red Cross.

It secured and operated 400 motor vehicles for the distribution of supplies in France.

It established a casualty service for gathering information in regard to wounded and missing.

It appropriated $600,000 for the relief of Belgian children, covering their removal from territories under bombardment, and the establishment and maintenance of them in colonies.

It provided the Italian army with three complete motor ambulance sections comprising 60 ambulances, 40 trucks, and 100 American drivers.

It supplied 1,000,000 surgical dressings and opened relief headquarters in nine regional districts in Italy.

It started reconstruction work in reconquered territory to supply repatriates with temporary dwellings, tools, furniture, farm animals, and the other supplies essential to give them a fresh start in life.

It opened a hospital and convalescent home for the repatric children at Evian; also established an ambulance service for the adult repatries who are now returning from points within the German lines at the rate of 1000 a day.

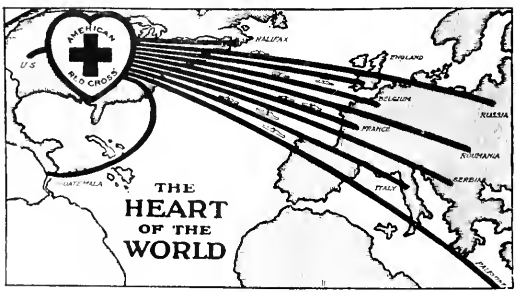
The absolute need for the continuance and extension of these activities is self-evident, yet we feel impelled to emphasize the fact by means of a "close-up" word-picture of the characteristically inhuman Teuton operations with which the Red Cross had to contend in carrying on the work of the last two items just listed.

"Two such trains [of repatriates from France and Belgium to be received back into France] pull into Evian every day. They are laden with the too-young and the too-old—unfit grist for the Prussian industrial mill. Kultur weighs its victims only in the scales of possible usefulness to the Vaterland. The humans in its power are reduced to terms of thaler, mark, and pfennig. The grandchildren too young to work and the grandparents too old to work for Germany are cast into the discard and loaded for France. Germany needs its food. It cannot afford to reduce the rations of its fighting men by feeding, however meagerly, useless children and equally useless old people. If they have to starve it were better they starved in France. And starve many of them unquestionably would were it not for Evian, Troche, and the Red Cross."

"There is another class of repatriates—the military prisoner. He is sent to France through Switzerland by the trainload daily; and nowhere in its campaign for world domination has Prussianism displayed its marvelous efficiency in so graphic a way. Without exception these repatriates won their release from Germany by toiling under duress until not one ounce of energy was left in them.

As has been pointed out, Germany weighs enemy man-power to the gram. She has many prisoners; why conserve their strength when she has such numbers on which to draw? It is higher efficiency, argues Kultur, to draw a prisoner's lifeblood quickly by working him at top speed on bran and water until the emaciated form and glassy eye tell the medical efficiency expert that the prisoner can be of no more use to the Kaiser. Then he is sent to France to die." (From "What Our Red Cross is Doing in France," *Review of Reviews*, December, 1917.)

However, neither figures nor words can tell the whole story, but they should be sufficient incentive for us to give generously to the Second Red Cross War Fund that not even a strand be broken in the "*Great Net of Mercy Drawn Through an Ocean of Unspeakable Pain.*" **Contribute.**



The Polyphase Shunt Motor

By W. C. K. Altes

Induction Motor Engineering Department, General Electric Company

In previous issues of this magazine, Mr. Altes has dealt with the theory and practical features of the various forms of the single-phase commutator motor and of the alternating-current *series* motor ("Single-phase Alternating-current Motors," July 1916, p. 579; "Theory of the Single-phase Alternating-current Motor," December 1916, p. 1072, Jan. 1917, p. 86; "Brush-Shifting Polyphase Series Motor," Feb. 1916, p. 115, March 1916, p. 199). In the article below, which is an abstract of a paper presented in Feb. 1918, at the Sixth Midwinter Convention of the A.I.E.E., he treats of the various forms of the alternating-current *shunt* motor. In the analysis of these various types of adjustable-speed motors, he shows (1) that the neutralized motor with shunt-field control is not practical for operation on commercial frequencies on account of the expensive control equipment required; (2) that the induction motor with a commutator on the secondary, while applicable in large sizes, is still too complicated for ordinary machine-tool drives; and (3) that the induction motor with a commutator on the primary side is the most suitable for driving these machine tools.—Editor.

Introduction

As far as generation, transmission, distribution, and constant-speed motor drives are concerned, the alternating-current system is far superior to the direct-current system.

The development of modern tungsten lamps has practically done away with arc lamps, so that both the alternating-current and the direct-current systems are equally suitable for lighting.

The development of speed-regulating sets has made it possible to regulate efficiently the speed of induction motors up to several thousand horse power.

The varying speed alternating-current brush-shifting motors, which have recently been put on the market, can be applied to variable speed pumps, blowers, exhausters, and certain textile machines.

The single-phase crane motor opens up possibilities in regard to dynamic braking, simplicity of control, and operation over a wide range of speed, which cannot be met by the induction motor with resistance control.

The adjustable-speed alternating-current motor makes it possible in plants requiring adjustable-speed motors for machine tool, elevator service, etc. to use the alternating-current system throughout if desired; but due to the fact that the alternating-current adjustable-speed motor is more costly than the direct-current adjustable-speed motor, it will be more economical to install machinery for changing over the alternating current to direct current, as long as a large number of motors is involved. However, the general tendency to standardization and centralization increases the number of processes which are carried on at constant speed, and call for the simple squirrel-cage induction motor and the use of the alternating-current adjustable-speed motor, in cases where only a limited number is required, will make it possible to extend the application of the squirrel-cage motor.

It is not intended to deal in this article with all the different types of alternating-current adjustable-speed motors which have been proposed by the various engineers that have worked on the problem. The article will be limited to the types that now seem most important. It is of value to the specialist to know the large number of possible combinations, so that he can use them when the constantly varying conditions make this possible, but engineers in general need interest themselves only in those schemes which are at present suitable for practical application.

Neither is it necessary to discuss the multi-speed induction motor, the speed of which is adjusted by connecting, to the line, windings wound with different numbers of poles. The field of application and the theory of this motor are well known. As long as only a few definite speeds are required, it is very satisfactory. However, there are a number of cases for which either a large number of speeds is required, or the desired speeds cannot be obtained with the possible numbers of poles. In these cases, one of the following types of alternating-current adjustable-speed commutator motors can be used:

(1) The neutralized polyphase commutator conduction motor.

(2) The induction motor with commutator on the secondary side.

(3) The induction motor with commutator on the primary side.

Neutralized Polyphase Commutator Conduction Motor

This motor consists of a direct-current armature winding, on the commutator of which is arranged a polyphase system of brushes, connected to a neutralizing winding which neutralizes the magnetomotive force of the armature winding and is connected to the line. The field winding is connected to the secondary of a transformer, the primary of which is connected to the line. It can be arranged in the same slots as the neutralizing winding, in which case the leakage flux will induce in the field winding a voltage proportional to and in phase with the leakage reactance voltage in the neutralizing winding. The motor field flux in this case lags ninety degrees behind the vector difference of the line voltage and the reactance drop induced in the field winding by the primary leakage flux which is yielded by the ampere-turns of both the field and neutralizing winding. The characteristics of the motor can be determined by considering that the neutralizing winding has no reactance drop, but that a reactance equal to the reactance of the neutralizing winding has been connected between the line and the motor terminals to which both the neutralizing winding and the field winding are connected. The field winding excites a rotating field, so that at synchronous speed the armature voltage and the voltage in the armature coils short-circuited by the brushes is zero, while this voltage increases when running above or below synchronous speed.

The field winding can also be arranged in other slots than those of the neutralizing winding. The field flux in this case lags ninety degrees behind the applied line voltage and the reactance drop of the neutralizing winding should be added to the reactance drop of the armature winding, which means that the difference between the no-load and full-load speed will be greater than before. The neutralized motor with the field winding in the same slots as the neutralizing winding is to the one with the field winding in other slots, as the direct-current shunt motor with resistance in series with the entire motor is to the direct-current shunt motor with resistance in the armature winding. This can be seen from the vector diagrams.

Fig. 1 gives the vector diagram for the neutralized motor with the field winding in the same slots as the neutralizing winding. OM represents the current which flows through both the neutralizing and the armature winding; NO the current in the field winding. Assuming that the field winding and neutralizing winding have the same number of turns w_1, then the primary leakage flux will be yielded by $NM \times w_1$ ampere-turns and the reactance drop AB induced by the leakage flux in both the neutralizing and field winding will lag ninety degrees behind NM. The resistance drop of the field winding FB is opposite to the field current NO. FO is the voltage induced in the field winding by the alternation of the field flux. AB, BF, and FO balance the applied line voltage OA. For the circuit consisting of the neutralizing and armature winding in series, the applied line voltage OA is balanced by the leakage reactance drop AB of the neutralizing winding, the resistance drop BE of the neutralizing winding which is opposite to the current OM, the reactance drop ED of the armature winding lagging 90 deg. behind OM, the resistance and brush-drop of the armature winding DC opposite to the current OM, and the counter e.m.f. CO which is induced by the field flux yielded by the field winding in space quadrature to the phase under consideration; and it is proportional to the speed, the number of armature turns, and the field flux. Due to the pulsation of the field flux, a voltage OF will be induced in both the neutralizing and the armature winding. If the neutralizing and armature winding have the same number of turns, then the voltage in the armature winding will be neutralized by the voltage in the neutralizing winding and the resultant voltage appearing at the terminals will be zero. This voltage

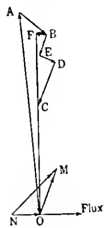


Fig. 1

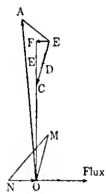


Fig. 2

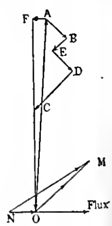


Fig. 3

appears, however, when measuring the drop across the brushes and across the terminals of the neutralizing winding individually. The core loss has been neglected in this diagram; it causes the flux to lag behind the ampere turns. The output is proportional to

$OC \times OM \times \cos. COM$. Fig. 1 has been drawn for operation below synchronous speed.

Fig. 2 gives the corresponding diagram when the motor is running at synchronous speed. It has been drawn under the assumption that the leakage reactance of the armature is proportional to the slip. In this case, the rotor reactance is zero at synchronous speed and the points D and E come together. The voltage applied to the field winding is equal to the vector connecting A with a point H on OF, so that $OH = FC$. This vector is not shown in Fig. 2.

Fig. 3 covers the diagram for a motor in which the field winding is located in other slots than those of the neutralizing winding. AB lags now 90 deg. behind OM instead of NM, and the leakage flux yielded by the neutralizing winding does not induce any voltage in the field winding.

Fig. 4 is similar to Fig. 3, except that the motor is running above synchronous speed in which case the rotor reactance appears negative. The voltage to be applied to the field winding has not been shown, but can be found by connecting A with a point H on FC, so that

$$FH = \frac{n_o}{n} OC$$

if n is the speed of the motor and n_o the synchronous speed.

In case the load is taken off the motors covered by Fig. 1 and Fig. 3, the speed will change as OC to OF. Due to the location

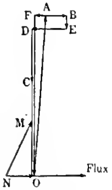


Fig. 4

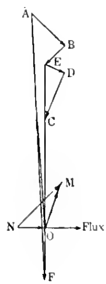


Fig. 5

of the drop AB, the variation in speed will be larger in the latter than in the former case. Hence, as far as the variation between the no-load and the full-load speed is concerned, it is better to arrange the field winding in the same slots as the neutralizing winding. However, by locating the field winding in other slots than those of the neutralizing winding, the field winding can be built with definite neutrals like a direct-current motor, so that in the coils short-circuited by the brushes no voltage is induced by rotation through the main field flux. Moreover, at these neutral points can be located the windings that excite the "commutating flux," inducing in the armature coils short-circuited by the brushes a voltage which both neutralizes the voltage induced by the alternation of the field flux and furnishes the e.m.f. required to reverse the current in the coils passing the brushes. Furthermore, it is possible to improve the speed-torque characteristics by using a series transformer, the secondary of which is connected to the field circuit and shifts the time phase of the flux depending on the load current drawn from the line. The characteristics of this motor are particularly favorable when running far above synchronous speed. Fig. 4 shows how the reactance of the neutralizing winding can be completely compensated by a negative reactance drop of the armature winding, but when predetermining the characteristics it must be borne in mind that the voltage induced by the commutating pole shifts the point at which the rotor reactance becomes negative to a higher speed, than in a motor which has no commutating poles.*

With the most generally used frequency of 60 cycles, it is impossible to take advantage of these favorable operating characteristics above synchronous speed unless the motor be connected to the secondary of an induction motor, in which case the commutator motor can be supplied with both a low frequency and a low voltage, and use made of it to control the speed of the induction motor. This has recently been done with great success and has led to a very important development of alternating-current commutator motors. A discussion of the various connections and possibilities of this application properly belongs to the subject of speed control of large induction motors and lies outside the scope of this article.

The motor, with the field winding located in the same slots as the neutralizing winding, is more suitable for operation below synchronous speed and can be used directly on 60-cycle circuits. Instead of building it with a separate field winding, the neutralizing winding can serve at the same time as field

*See H. Meyer-Delius, GENERAL ELECTRICAL REVIEW, 1913 page 976.

winding which only slightly changes the diagram, as can be seen by comparing Fig. 1 with Fig. 5, which has been drawn for a motor in which both field and neutralizing winding have been combined in one. The vector AB is equal to the leakage reactance

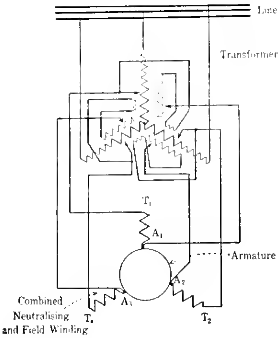


Fig. 6

drop in the neutralizing winding which lags 90 deg. behind NM; BE is the resistance drop of the neutralizing winding; EF is the voltage induced in the neutralizing winding by the alternation of the field flux; FE the voltage induced in the armature winding by the alternation of the field flux; ED the reactance drop; DC the resistance drop; and CO the rotation voltage induced in the armature winding. The measured voltage across the neutralizing winding is equal to AF, the one across the armature winding reduced to the phase-voltage of the equivalent Y connection FO. The resultant of AF and FO gives the line voltage AO. Thus, it is seen that below synchronous speed, the voltage across the neutralizing winding is higher than the line voltage per phase until F and O are at the same point, which occurs slightly below synchronous speed.

The diagram of connections of a motor covered by the vector diagram of Fig. 5 is shown in Fig. 6. Speed regulation can be obtained by connecting the terminals T_1, T_2, and T_3 to different taps of the transformer which changes the terminal voltage applied to the motor, or by changing the points to which the armature terminals A_1, A_2, and A_3 are connected which changes the field flux, or by both. The principal disadvantage of this motor is that the transformer has to be designed for its full kv-a. capacity. In order to obtain satisfactory commutation, the armature must be built for a low voltage, which in general makes the ratio of the applied line voltage to the secondary voltage high, so that the size of the transformer is not materially reduced by building it as a compensator. Instead of using the neutralizing winding also as field winding, the armature can serve for this purpose. Fig. 7 gives the diagram for this arrangement. In this case OM is the current in the neutralizing winding, NM the current in the armature winding. The volt-amperes required for exciting the field is equal to $FO \times NO$ of Fig. 7 instead of $AF \times NO$ of Fig. 5, as is the case when the field current flows through the neutralizing winding. When running at a lower speed than 50 per cent above synchronous speed, the field can be excited with less volt-amperes by using the armature, instead of the neutralizing winding, as field winding, which results in a small reduction in the size of the regulating transformer and an improvement of the power factor. It is also possible to excite the field by current flowing partly through the field winding and partly through the armature winding, which can be done by impressing voltage of the proper time-phase on both the neutralizing and the armature winding. However, all these schemes, with the exception of the one where the commutator motor is connected to the secondary of an

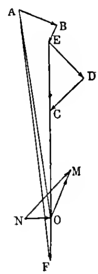


Fig. 7

induction motor, have the disadvantage that a large transformer is required for the main circuit. The size of this transformer can be reduced by using the following type of motor.

Induction Motor with Commutator on the Secondary

In this type of motor, the armature reaction is neutralized by induction instead of by conduction. It is clear that the operation of the motor covered by Fig. 5 and Fig. 6 will not be changed, if the neutralizing winding is separated from the armature winding provided there is impressed on the neutralizing winding the voltage AF and on the armature winding the voltage FO. The number of turns of the neutralizing winding can then be increased, so that the winding can be connected directly across the line while the armature is connected to a rotor-transformer which supplies the voltage OF. A brush-shifting series motor can then be taken, its brushes put in the neutral, and the primary of the rotor-transformer connected to different points of the stator winding. In this way, there results a motor which has the same characteristics as a neutralized motor, operated with a constant field flux and a variable voltage applied to the terminals.

Fig. 8 gives the diagram of connections which is suitable for a motor having four poles, or a multiple thereof. Four poles have been connected in series and a tap is brought out at each pole. (The taps have not been shown in the diagram.) This gives four speeds below and four speeds above synchronous speed, in addition to the synchronous speed, and requires thirteen stator terminals. The transformer should be built with a relatively low impedance drop, in order not to spoil the regulation. This can be done as long as only a small variation in

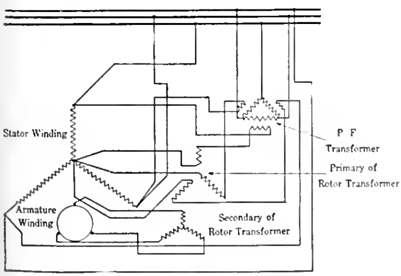


Fig. 8

speed is required. For instance, if it is desired to regulate the speed 25 per cent below and 25 per cent above the synchronous speed, the capacity of the transformer is equal to only 25 per cent of the kilovolt amperes flowing through the motor. The characteristics can be improved by adding a small transformer to shift the time-phase of the voltage impressed on the primary of the rotor transformer.

On small motors, the rotor transformer can be omitted and the stator can be equipped with both a main winding connected to the line and a regulating winding connected to the armature winding. This can be done in various ways.*

In all the motors thus far described, the frequency of the rotor currents is reduced to line frequency by means of a commutator connected to the rotor winding, which makes it possible to combine the voltage induced in the rotor with a voltage derived from the line. It is possible to build a satisfactory motor in this way. However, the complicated control which it requires makes it rather unsuitable for the American market. The motor covered by Fig. 8 may find a limited application in special cases, although too complicated for general application to machine tool work.

The machine tool builders require an alternating-current motor which can be installed as easily as a direct-current motor and the speed of which can be changed in a simple manner. In this respect, the following type of motor is more promising.

The Induction Motor with Commutator on the Primary Side

Instead of changing over the rotor frequency to the line frequency, there can be added to the motor a frequency changer which makes available at every speed a voltage of the same frequency as the voltage induced in the secondary. This can be done by taking a synchronous converter armature, running in a laminated field, and driven by the motor of which the speed must be regulated. With the slip rings of the synchronous converter connected to the line and a proper selection of the number of poles and the speed ratio between the shaft of the motor and frequency changer, the frequency of the voltage appearing at the commutator will be proportional to the line frequency times the slip. The ratio of the voltage applied to the slip rings to the one appearing at the commutator is independent of the speed. If two movable brush yokes are connected to the secondary of the induction motor, by changing the relative positions of these yokes there can be impressed on the

*See F. Eichberg, *Elektrotechnische Zeitschrift*, 1910, p. 749, E. Arnold, *Die Wechselstromtechnik*, Bd. V₂ secondary, voltages of different time-phase and amount and the speed of the induction motor can be regulated, both below and above synchronous speed. If c is the ratio of the number of turns of the winding of the converter to the secondary winding and n_o

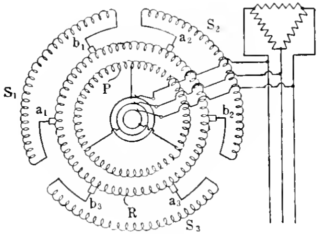


Fig. 9

is the synchronous speed, then the approximate speed range at no load varies between $n_o(1-3)$ and $n_o(1+c)$.

It is possible to combine the frequency changer and the induction motor, if the induction motor primary winding is located on the rotor and connected over slip rings to the line. In this case the frequency changer which will be denoted as regulating winding, does not need to be connected to the line, but its coils can be located on the rotor in the same slots as the primary winding, so that the primary flux induces the voltage in this regulating winding. The secondary is located on the stator and can be built with any number of independent phases, provided each yoke is equipped with the proper arrangement of brushes to correspond to this number of phases. The diagram of connections of a motor of this kind, having three independent secondary phases has been shown in Fig. 9.* The brushes A_1, A_2, and A_3, are mounted on one yoke and the brushes B_1, B_2, and B_3 on another yoke. The motor will operate as an induction motor with short-circuited secondary when the brushes A and B are on the same commutator bar. Both yokes are moved 90 electrical degrees each way from this middle position, the yokes moving in opposite directions. In this manner, regulation both above and below synchronous speed can be obtained. The voltage across every commutator bar is independent of the speed and is proportional to the flux, the frequency, and the number of turns in series. If a motor with the highest possible flux is to be built without exceeding the safe limits for the voltage per bar, a single-turn multiple armature should be used. But even with this winding, the maximum permissible flux is still low, so that this type of motor cannot be built for more than 5 h.p. per pole for 60 cycles and 12 h.p. per pole for 25 cycles, no matter what the speed range is, with the exception that the commutation below synchronous speed is sufficiently better than above that if use is not to be made of the above-synchronous speed range a higher voltage per bar and a larger output per pole can be employed. In general, the small output per pole which can be obtained is no serious drawback, as most motors for machine tool and elevator work are geared and consequently built for low speed.

On the commutated induction motor with the commutator on the secondary side, the voltage across the commutator bars is proportional to the flux, the number of turns, and the frequency of slip. Therefore, if this motor is built for a small speed range, a larger field flux can be used, and there can be obtained with 60 cycles and 20 per cent regulation above and below synchronous speed, 30 h.p. per pole, and with 25 cycles 75 h.p. per pole. This is only possible as long as the required starting torque is low, so that the motor must be started with reduced field flux to avoid excessive sparking.

On the commutated induction motor with commutator on the primary side, the voltage across the commutator bars at starting is the same as at running and high starting torque can be developed without any danger to the commutator. This fact makes this motor particularly suitable for reversible operation.

It has been explained in the foregoing that it is possible to use a larger output per pole by having the commutator on the secondary instead of on the primary side. However, as long as the limitations of the output per pole are not exceeded and there is 50 per cent regulation both above and below synchronous speed, it is much better, from a commutation standpoint, to use the second scheme. In building motors of the same output in both ways, equal field fluxes would naturally be used. This means that the regulating winding of the induction motor with the commutator on the primary side will have one turn per coil, while the armature winding of the induction motor with the commutator on the secondary side will have

*This diagram is the one of the Schrage Patent 1,079,994.

two turns per coil. This will give the same sparking voltage at half speed and 50 per cent above synchronous speed for both motors.

It is clear that the commutation conditions, as far as the current commutation is concerned, are much better in the former case than in the latter, as there is a one-turn armature and a lower slot reactance due to the fact that the regulating winding fills only part of the slots. The current commutation is the limiting feature above synchronous speed and, for this reason, the induction motor with commutator on the primary side can be built for a greater speed range above synchronous speed than the one with commutator on the secondary side. This is a great advantage, because the speed-torque characteristics and the maximum output of the motor are much more advantageous above than below synchronous speed. This partly offsets the limitation as to the maximum output per pole obtainable, as the reduction in speed resulting from the necessity of using a large number of poles is counteracted to a large extent by the possibility of raising the speed considerably more above synchronism.

The theory of the induction motor with commutator on the primary side can be explained with the aid of the same diagrams as have been given for the other motors. The following derivation of the diagrams made in a different way and some of the equations used in predetermining the characteristics may be of interest.

In the approximate theory of the induction motor, the exciting current is considered constant* and as flowing through a separate exciting circuit. By doing this, a very slight error is made as there is neglected the impedance drop of the exciting current, thus figuring with a flux which is slightly larger than the actual flux, and there is used too high a value for the exciting current. The approximation simplifies the calculation considerably and will be used in the following. In Fig. 10 is the approximate vector diagram for the induction motor. It is seen that for the primary circuit the applied voltage $OH = E_l$ is balanced by the primary resistance and reactance drop $HA = I_0 r_0$, and $AB = I_0 x_0$, and the voltage $BO = E_0$ induced by the main flux. After having reduced secondary turns to the primary turns, it is found that the same voltage $BO = E_1$ is induced in the secondary and that this voltage is balanced by the secondary reactance drop $DE = I_1 s x_1$, the secondary resistance drop $OD = I_1 r_1$, and the counter e.m.f. $EB = (1-s)\ E_1$. If we draw $QR \parallel FD$, $EF \perp BA$, and $QF \perp HA$ then $OQ = sE_1$

*See Steinmetz's *Alternating-current Phenomena.*

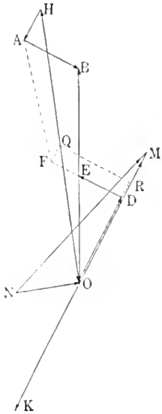


Fig. 10

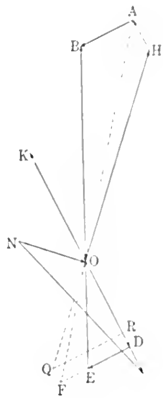


Fig. 11

Let

$$OQR = i \text{ then } \tan i = \frac{OR}{QR} = \frac{r_1 + s\, r_0}{s\, x_1 + s\, x_0} = \frac{\frac{r_1}{s} + r_0}{x_1 + x_0}$$

and

$$I_1 = \frac{E_1 \sin i}{\frac{r_1}{s} + r_0}$$

The torque per phase in synchronous watts equals

$$OB \times I_1 \times \cos BOD = \frac{OD}{s} I_1 = \frac{I_1^2 r_1}{s}$$

The line current I_l is equal to the vector sum of I_1 and the exciting current I_m, which lags 90 deg. behind OH, provided hysteresis is neglected. Thus, the wattless component of the line current is equal to $I_w = I_m + I_1 \cos i$ the watt component $I_1 \sin i$ and the total line current

$$I_l = \sqrt{I_m^2 + I_1^2 + 2\, I_m I_1 \cos i}$$

When the induction motor is driven above synchronous speed as an induction generator, the diagram assumes the form of Fig. 11. The counter e.m.f. B is now larger than the induced voltage BO. There has to be taken into account besides that, the fact that the rotating field in the rotor has changed its direction, so that the time axis for the rotor rotates counter clockwise while the time axis for the stator continues to rotate clockwise. For the counter clockwise rotating time axis of the rotor, the secondary reactance drop DE lags 90 deg. behind the current. This secondary reactance drop appears as a negative reactance drop, however, when reduced to the primary circuit in which the time axis rotates clockwise.* A complete calculation of an induction motor in accordance with the above method has been given in Table I. It will be noted that this method is the same in principle as the approximate "Steinmetz method."

The induction motor with commutator on the primary side can be calculated in a similar manner. If the primary and the regulating winding are located in the same slots, the leakage between these two windings is so small that it can be neglected. The vector sum of the ampere-turns resulting from the currents in both the primary and the regulating winding will yield a leakage flux, which induces in the primary winding a voltage c_x and in the regulating winding a voltage ce_x if c is the ratio of the number of turns of the regulating and the primary winding.

In order to find how the reactance should be taken into account, investigate the conditions at standstill and consider the motor as a quarter-phase stationary trans-

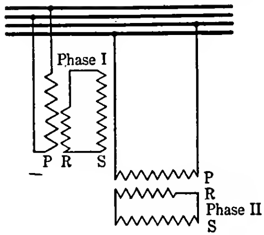


Fig. 12

former having a primary winding P, a regulating winding R, and a secondary winding S. The windings P and R are fitted in between each other, so as to have only a small leakage between the two. R and S are connected together. Let P and S have the same number of turns, and the ratio of turns of R and S be c. Assuming as

*Dr. Rudenberg has called particular attention to this point in the *Elektrotechnische Zeitschrift*, 1910, p. 1087.

TABLE 1

s	0.01	0.0159	0.02118	−0.01	−0.0159	−0.02118
r_1	0.041575	0.041575	0.041575	0.041575	0.041575	0.041575
r_0	0.033778	0.03378	0.03378	0.03378	0.03378	0.03378
$\frac{r_1}{s}$	4.1575	2.619	1.968	−4.1575	−2.619	−1.966
$r_0 + \frac{r_1}{s}$	4.19275	2.6528	2.00178	−4.1238	−2.58522	−1.932
$x_0 + x_1$	0.2764	0.2764	0.2764	0.2764	0.2764	0.2764
$\tan i = \frac{r_0 + \frac{r_1}{s}}{x_0 + x_1}$	15.15	9.59	7.52	−14.9	−9.36	−6.98
i	86° 13′	84° 3′	82° 25′	273° 83′	263° ′53′	261° 51′
$\cos i$	0.0658	0.1036	0.1320	0.06685	0.1067	0.1422
$\sin i$	0.9978	0.9946	0.9912	−0.9977	−0.9943	−0.9899
Et	317.5	317.5	317.5	317.5	317.5	317.5
$I_1 = \frac{Et \cos i}{x_0 + x_1}$	75.6	119.0	151.5	76.5	122.2	163.2
or $I_1 = \frac{Et \sin i}{r_0 + \frac{r_1}{s}}$	75.6	118.8	157	76.8	122.	162.2
$D = \frac{I_1^2 r_1}{s}$	23,750	36,850	48,400	−24,400	−39,000	−51,800
I_m	59.6	59.6	59.6	59.6	59.6	59.6
$I_1 \cos i$	4.97	12.36	20.74	5.1	13.01	23.06
$I_{wl} = I_m + I_1 \cos i$	64.57	71.96	80.34	64.7	72.61	82.66
I_h	4.615	4.615	4.615	4.615	4.615	4.615
$I_1 \sin i$	75.4	118.1	155.8	−76.3	−121.1	−160.2
$I_w = I_h + I_1 \sin i$	80.015	122.715	160.42	−71.685	−116.48	−155.585
I_{wl}^2	4,165	5,170	6,450	4,200	5,280	6,835
I_w^2	6,400	15,010	25,750	5,150	14,700	24,190
$(I_w^2 + I_{wl}^2)$	10,565	20,180	32,200	9,350	19,980	31,025
$Il = \sqrt{I_w^2 + I_{wl}^2}$	102.8	142	179.5	96.5	141.2	176.2
$P_1 = D\ (1 - s)$	23,500	36,250	47,400	−24,600	−39,600	−52,950
F_0	607	607	607	607	607	607
Mech. Output $= P = P_1 - F_0$	22,893	35,643	46,793	−25,207	−40,207	−53,557
Input $= I_w\ Et$	25,400	38,900	50,900	−22,760	−36,980	−49,300
Eff. $= \frac{P}{I_w\ Et}$	90.2	91.7	92.0	90	91.9	92.1
P. F. $= \frac{I_w}{Il}$	78.0	86.3	89.5	93.7	95.2	95.7
H. P. $= \frac{3\ P}{746}$	92.0	143.7	188.0	102.3	161.8	215.4

before that the magnetizing current flows in a separate circuit, the ampere-turns yielded by P and R must be equal and opposite to the ampere-turns yielded by S. Hence, the current flowing in P of Fig. 12 is equal to $(1-c)\ I_1$. The primary leakage flux is yielded by the vector sum of the ampere-turns of P and R, which is equal and opposite to the secondary ampere-turns resulting from I_1 flowing through S. This primary leakage flux is interlinked with the turns of P and causes the resistance drop $AB = I_1 x_0$, if x_o is equal to the leakage reactance of P considered as the primary of an induction motor. Fig. 13 gives the vector diagram when neglecting the primary resistance drop. In the primary winding P, the line voltage OA is balanced by the reactance drop $AB = I_1 x_0$ and the induced voltage BO. The voltage across the regulating winding will be equal to $OC = cOA$ and in the secondary circuit the induced voltage BO is balanced by the reactance drop DB, the resistance drop CD, and the voltage OC across the regulating winding. This voltage is the vector sum of the voltage induced by both the main and the leakage flux. The secondary current $OK = I_1$. The primary load current is equal to $-(OK - KL) = -(I_1 - cI_1) = OM$. The exciting current NO added at right angles to OA results in the line current $I_l = NM$. The secondary resistance drop

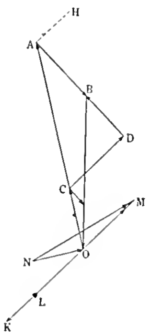


Fig. 13

CD should include the brush drop and the resistance of both the secondary and the regulating winding. If desired, the resistance drop of the primary load current which is equal to $(1-c)I_1 r_0$ can easily be added, as shown by the dotted line AH. If $c = 0.5$, the primary load current is equal to $0.5\ I_1$ and the ampere-turns of the primary are equal to those of the regulating winding. In this case, the minimum copper loss will be obtained if the copper-cross-sections of both windings are made equal. When running

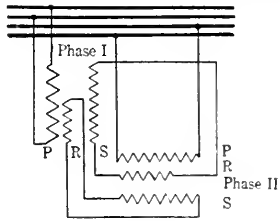


Fig. 14

ning above synchronous speed, the ampere-turns of the primary winding are equal to the sum of the ampere-turns of both the regulating and the secondary winding, hence in order not to have the primary winding overheat when running above synchronous speed, it is better to make the cross-section of the regulating winding smaller than those of the primary winding. As $AC = (1-c)E_l$, the reactance $(x_0 + x_1)$ is found by an impedance test applying E_l to the slip rings

$$x_0 + x_1 = \frac{E_l(1-c)}{OM} \sin ACD$$

or approximately:

$$x_0 + x_1 = \frac{E_l(1-c)^2}{I_l} \sin ACD$$

It is clear that the condition described corresponds to the induction motor with the brushes in the neutral. Also the secondary of phase I can be connected to the regulating winding of phase II and the secondary of phase II to the regulating winding of phase I, as is shown in Fig. 14. The vector diagram of this arrangement is shown in Fig. 15. In this case, the resultant voltage, which overcomes the impedance drop, is equal to

$$AC = E_l\sqrt{1+c^2}$$

and

$$x_0 + x_1 = \frac{E_l(1+c^2)}{I_l} \sin ACD$$

This corresponds to the commutated induction motor with a brush-shift of 90 deg.

Fig. 16 gives a similar diagram for a brush-shift b in which case the resultant voltage is equal to

$$AC = E_l\sqrt{1+c^2-2c\cos b}$$

and

$$x_0+x_1=\frac{E_l\,(1+c^2-2\,c\cos b)}{I_l}\sin ACD$$

All the foregoing equations for x_0+x_1 have been given without taking the primary resistance loss, the core loss, and the magnetizing current into account. This is satisfactory as long as the impedance test is made at greatly reduced voltage. If necessary, these values can be taken into account as follows: Read primary watts (W), amp. (I_l), and volts (E_l).

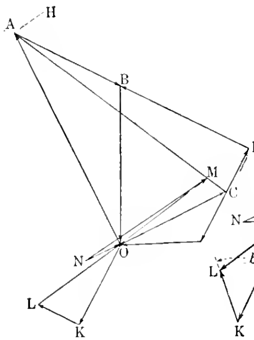


Fig. 15

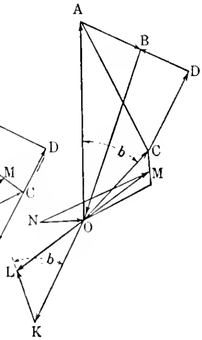


Fig. 16

Determine $I_w=I_l\cos\phi$ and $I_{w1}=I_l$ sine ϕ.
Determine at standstill with open secondary I_m for a voltage E_l and subtract I_m from I_{wl} then the secondary current reduced to the primary is equal to

$$I_1=\frac{\sqrt{(I_{wl}-I_m)^2+I_w^2}}{\sqrt{1+c^2-2\,c\cos b}}$$

The secondary impedance is

$$z_l=\frac{E_l(1+c^2-2\,c\cos b)}{\sqrt{(I_{wl}-I_m)^2+I_w^2}}$$

Let the core loss with E_l volts applied to the slip rings be W_c watts and the primary resistance loss with a current I_l, be $3\,I_l^2r_0$ then

$$r_1=\frac{W-W_c-3\,I_l^2r_0}{3\,[(I_{wl}-I_m)^2+I_w^2]}\,(1+c^2-2\,cs\cos b)$$

and

$$x_0+x_1=\sqrt{z_1^2-r_1^2}$$

A comparison of Fig. 16 and Fig 13 shows that, due to the shift b, the secondary current $I_1=OK$ is shifted into the direction of the secondary induced voltage BO. This means that with the same flux and the same secondary current there results a higher torque. The possibility of shifting the time-phase of the secondary current by means of the brush-position can be utilized for obtaining a higher torque per ampere than is possible with the induction motor with resistance in the secondary. The fact that the secondary current at the same time flows through the regulating winding, and thereby reduces the primary current, makes this condition still better.

Fig. 17 is also drawn for a brush-shift b, only in this case the motor is running and a counter e.m.f. EB is induced in the secondary. The resultant voltage in the secondary is equal to $EO=BO-EB$. If EF is drawn $\parallel AB$ then

$$\frac{OF}{OA}=\frac{OE}{OB}=\frac{s}{1}\text{ or } OF=s\,E_l$$

Further

$$FE=s\,AB=s\times x_0I_1$$

$$FC=\sqrt{FO^2+OC^2-2\,FO\times OC\cos FOC}$$
$$=E_l\sqrt{s^2+c^2-2\,c\,s\cos b}$$

Let

$$OFC=a\text{ and }CFD=i$$

then

$$\frac{\sin a}{OC}=\frac{\sin b}{FC}\text{ or }\sin a=\frac{c\sin \mathrm{b}}{\sqrt{s^2+c^2-2\,cs\cos b}}$$

$$\tan i=\frac{DC}{FD}=\frac{r_1}{s(x_0+x_1)}$$

The secondary current is equal to

$$I_1=\frac{FC\sin i}{r_1}=\frac{E_1\sin i\sqrt{s^2+c^2-2\,c\,s\cos b}}{r_1}$$

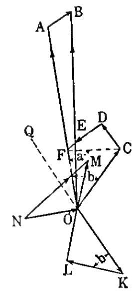


Fig. 17. Running as Motor below Synchronous Speed—Brush Shift Opposite to Direction of Rotation

The torque per phase in synchronous watts is equal to

$$D=BO\times OK\cos BOQ=OA\times OK\cos AOQ$$
$$AOQ=OFC-(90°-CFD)=a+i-90$$

or

$$\cos AOQ = \sin(a+i)$$

and

$$D = E_1 \times I_1 \sin(a+i)$$

The electrical output is equal to $P_1 = D(1-s)$. The mechanical output P is equal to the electrical output minus the friction and windage per phase, $P = P_1 -$ friction, windage. The primary current can be calculated by determining separately the component I_w in phase with the applied line voltage and the component I_{wl} which is 90 deg. out of time phase with the line voltage.

If I_h is the core loss current then:

$$I_w = I_h + OK \cos QOA - LK \cos(QOA + b)$$
$$I_w = I_h + I_1 \cos(a+i-90) - cI_1 \cos(a+i+b-90)$$
$$I_w = I_h + I_1 [\sin(a+i) - c \sin(a+i+b)]$$

If I_m is the wattless component of the magnetizing current then,

$$I_{wl} = I_m + OK \sin QOA - LK \sin(QOA + b)$$
$$I_{wl} = I_m + I_1 [\cos(a+i) - c \cos(a+i+b)]$$

The total line current is $I_l = \sqrt{I_w^2 + I_{wl}^2}$

The power factor $= \dfrac{I_w}{I_l}$

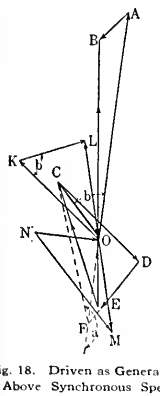


Fig. 18. Driven as Generator Above Synchronous Speed —Brush Shift Opposite to Direction of Rotation

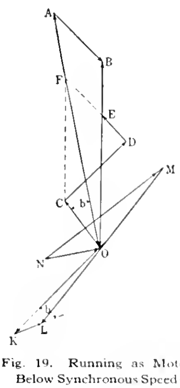


Fig. 19. Running as Motor Below Synchronous Speed — Brush Shift in the Direction of Rotation

The input $= E_l I_w$

The efficiency $= \dfrac{P}{E_l I_w}$

When determining the angles from the sine and tangent, some care must be taken to get the angle in the proper quadrant. This can be done readily as long as the possible variation of these angles with the slip is taken into account, with the aid of the diagram. For instance, it follows from Fig. 17 that F moves over AO from A to O when

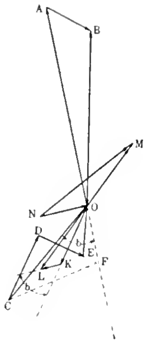


Fig. 20. Running as Motor Above Synchronous Speed Brush Shift in the Direction of Rotation

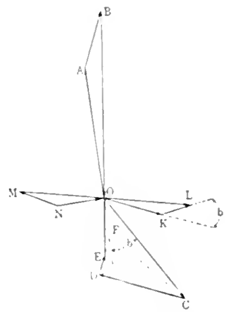


Fig. 21 Running as Motor Above Synchronous Speed — Brush Shift Opposite to Direction of Rotation

the slip changes from 1 to 0. The angle $CFO = a$ changes from an acute to an obtuse angle. Fig. 18 gives the diagram for the same brush position as used in the diagram of Fig. 17, when the motor is driven above synchronous speed. In case the motor is rotating counter-clockwise the field in the rotor will rotate clockwise. Hence, as long as operating below synchronous speed, the electrical field will rotate clockwise, in respect to both the stationary secondary winding and the stationary brushes connected to the commutator of the regulating winding. This means that if OC is to lag behind OA, as shown in Fig. 17, the brushes must be shifted in the direction of the rotation of the electrical field, *i.e.* opposite to the mechanical rotation of the rotor. When running above synchronous speed, the electrical field will rotate counter-clockwise with respect to both the stationary secondary winding and the brushes; and if the brush position remains unchanged, OC will lead OA. When reduced to the primary, for which the time axis rotates clockwise, OC will lag behind OA as in Fig. 17. This has been shown in Fig. 18. When running above synchronous speed, the secondary reactance drop appears negative when viewed from the primary as explained for the usual induction generator with short-circuited secondary. Table II gives a complete calculation made in accordance with this theory. It has been found that the theory is confirmed by test.

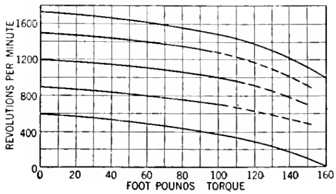


Fig. 22

Fig. 19 gives the diagram for a motor operating below synchronous speed when the brushes are shifted in the wrong direction, *i.e.*, in the direction of rotation. It will be noted that this results in a low secondary power-factor, which is always combined with a reduction in maximum output and larger variation between the no-load and full-load speed.

Fig. 20 gives the diagram for operation above synchronous speed. The counter e.m.f. *EB* is larger than the induced secondary voltage *BO* and the voltage *OC* of the regulating winding is impressed in opposite direction, being shifted over an angle *b* in the direction of rotation from the neutral position.

Fig. 21 gives the same diagram, only the brushes are shifted opposite to the direction of rotation which causes the secondary current to lead too much and results generally in inferior commutation. Instead of calculating the characteristics by means of simple geometrical equations, circle diagrams can be used.* Both the derivation and the application of these diagrams are rather complicated and, therefore, will not be given in this article.

Fig. 22 gives the tested speed-torque curves of a 440-volt, 3-phase, 1200-r.p.m., 60-cycle, brush-shifting motor built as an induction motor with the commutator on the primary side and on which the brushes are shifted 5 deg. opposite the direction of rotation in the slowest speed position and 5 deg. in the direction of rotation in the highest speed position. This has been done by shifting one yoke faster than the other, while both move in opposite direction, so that one yoke moves through 170 electrical degrees while the other yoke moves through 190 electrical degrees. This motor has been built for one direction of rotation. If the motor has to operate with the same characteristics in both directions of rotation, the brush-shifting mechanism becomes more complicated, as will be understood from Figs. 23 and 24, which give the desired brush-position for maximum and minimum speed in both directions of rotation for a two-pole motor. However, a simple mechanical solution has been found and a motor incorporating this scheme is now being tested. A photograph of it is shown in Fig. 27, and the brush-shifting mechanism is represented in Fig. 25. This motor has been built with four poles and a six-phase secondary, each yoke having 12 studs.

The fast moving yoke *B* on which the brushes *b*1, *b*2, and *b*3 have been mounted is supported by the bearing-housing. The slow moving yoke on which the brushes *a*1, *a*2, and *a*3 have been mounted is supported by the end shield; it is moved by means of a stud which connects it to the disk *C*, which is supported on the bearing housing.

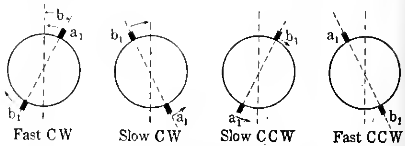


Fig. 23

b_1 moves through 360 $-2b$ deg. *CW*
a_1 moves through 360 $+2b$ deg. *CCW*. While b_1 moves through $2b$ deg. from slow *CW* to slow *CCW*, a_1 should move *CW* through $2b$ degrees

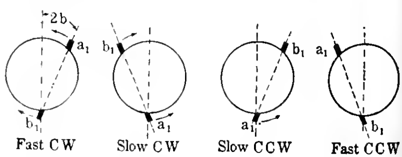


Fig. 24

b_1 moves through 360 deg. *CW*
a_1 moves through (360 deg. $+4b$) *CCW*. While b_1 moves through $4b$ degrees from slow *CW* to slow *CCW*, a_1 should stand still

The pinions *D* and *E* are keyed to a shaft which can rotate in a bearing supported by the disk *C*. The pinion *D* meshes with a gear *F* which is mounted on the bearing housing, and the pinion *E* meshes with a gear *G* which is fastened to yoke *B*. If the

*See O. S. Bragstad, *E. T. Z.*, 1903, p. 368; E. Arnold, *Die Wechselstromtechnik*, Bd. V2; H. Meyer-Delius, GENERAL ELECTRIC REVIEW, 1914, p. 817; H. K. Schrage, *E.T.Z.*, 1914, p. 81.

TABLE II

$r_s + x_t = 0.45 \quad I_m = 20 \quad c = 0.56$
$r_t = 0.30 \quad I_h = 1.1$
$E_t = 127 \quad b = 3.5°$

s	1.4	1.2	1	0.8	0.6	0.4	0.2	−0.2	−0.4	−0.6	−0.8	−1.
s^2	1.96	1.44	1	0.64	0.36	0.16	0.04	0.04	0.16	0.36	0.64	1
c^2	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314
$s^2 + c^2$	2.274	1.754	1.314	0.954	0.674	0.474	0.354	0.354	0.474	0.674	0.954	1.314
$2cs \cos b$	1.564	1.34	1.119	0.894	0.670	0.447	0.224	−0.224	−0.447	−0.670	−0.894	−1.119
$s^2 + c^2 - 2cs \cos b$	0.711	0.414	0.195	0.060	0.004	0.027	0.130	0.578	0.921	1.344	1.848	2.433
$\sqrt{s^2 + c^2 - 2cs \cos b}$	0.844	0.644	0.442	0.246	0.063	0.164	0.36	0.759	0.959	1.16	1.36	1.56
$I_{res} = I_h\sqrt{s^2 + c^2 - 2cs \cos b}$	107.2	81.7	56.0	31.1	8.03	20.84	45.8	96.1	122	147.2	172.7	198.0
$\sin a = \dfrac{c \sin b}{\sqrt{s^2 + c^2 - 2cs \cos b}}$	0.0425	0.0557	0.0811	0.146	0.565	0.218	0.0993	0.0471	0.0373	0.0308	0.0264	0.023
a	2°27′	3°12′	4°40′	8°25′	34°24′	167°23′	174°17′	182°42′	182°9′	181°46′	181°31′	181°19′
$\tan \varphi = \dfrac{r_t}{x + c \ldots}$	0.475	0.554	0.667	0.835	1.109	1.661	3.34	−3.31	−1.661	−1.109	0.845	−0.667
φ	25°27′	29° 0′	33°42′	39°51′	47°57′	58°58′	73°20′	−73°20′	−58°58′	−47°57′	−39°51′	−33°42′
$\cos \varphi$	0.428	0.484	0.553	0.640	0.741	0.857	0.958	−0.958	−0.857	−0.741	−0.640	[illegible]
$I_1 = \dfrac{E_t \ldots \sqrt{\ldots b}}{\ldots}$	153.2	132.1	103.2	66.3	19.8	59.7	116	−0.308	−348.1	−364	−368.2	[illegible]
[illegible]	27°52′	32°12′	35°22′	48°16′	82°21′	220°21′	247°37′	109°22′	123°11′	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.547	0.621	0.746	0.991	−0.724	[illegible]	0.943	0.847	0.721	[illegible]	[illegible]
[illegible]	[illegible]	9,180	8,140	6,270	2,494	[illegible]	−17,100	[illegible]	−37,000	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0	1,254	998	[illegible]	[illegible]	−44,200	−51,800	[illegible]	[illegible]	[illegible]
[illegible]	107	[illegible]	0	[illegible]	107	160	214	[illegible]	[illegible]	427	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	0	1,211	891	−148	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	51°46′	85°51′	220°51′	[illegible]	[illegible]	126°41′	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
m	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
I_m	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$P.F. =$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Input $= E_t \ldots$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Eff. $=$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]
When [illegible] varies from [illegible]
When [illegible] varies from 0 to [illegible]
Tables I and II have been calculat[illegible]

gear F is held stationary and the disk C is turned, both pinions D and E will rotate. Pinion E will drive the gear G fastened to yoke B. The gear ratio can be selected in such a manner that disk C and yoke A move in the opposite direction to yoke B

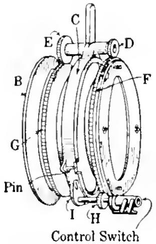


Fig. 25

and at a slower rate. The gear F is held by a pinion H which is keyed to the same shaft as the intermittent gear I, while this shaft rotates in a bearing which is rigidly supported from the bearing housing. The intermittent gear I is moved through a small angle when it is struck by a pin, which is fastened to the disk C. After the pin has moved it, I is held stationary by sliding on the outside circumference of C. When I is moved by the pin, H will turn through the same angle and move the gear F. By properly selecting the gear ratios, it is possible when changing from "slow" in one direction to "slow" in the other direction, to have yoke B remain stationary or move in the same direction as C, while the intermittent gear is moved by the pin. The former arrangement gives a change of brush-positions in accordance with Fig. 24, the latter in accordance with Fig. 23. A control switch is connected to the shaft to which I is connected and changes the phase-rotation of the lines to which the collector rings have been connected.

The induction motor with commutator on the primary side can be run single-phase, by opening one lead connecting to the collector rings. If only single-phase is available, it can be started like an ordinary single-phase induction motor by using a split-phase starting device, or as a repulsion motor in which case a higher torque can be obtained. This connection is shown in Fig. 26 for a motor having a quarter-phase secondary. One phase of the regulating winding is used as the primary of the repulsion motor, a resistance R keeps the line current down, and the connections are changed from starting to running by means of a three-pole double-throw switch. If the motor has a three-phase secondary, a four-pole double-throw switch is required.

In its original form, the induction motor with commutator on the primary side is wound with the primary winding in the bottom and the commutated regulating winding in the top of the armature slots. In this way, four coil ends have to be inserted in every slot, which takes up much room for the insulation. Moreover, if the primary winding has to be repaired, it is necessary to remove first part of the coils of the regulating winding. A winding is being developed which is arranged in such a manner that only two coil ends are located in one slot. If an even number of slots and a coil pitch equal to an odd number are used, the windings can be arranged in such a way as to have a primary coil in the top of every odd and in the bottom of every even slot, and a coil of the regulating winding in the top of every even slot and in the bottom of every odd slot.

The leads of the primary winding can be brought out on the back end and the leads of the coils of the regulating winding on the commutator end. The insertion of such a winding is no more difficult than the insertion of an ordinary lap winding, it merely being

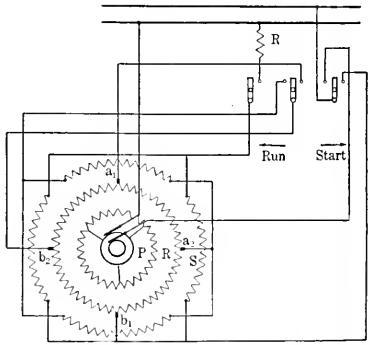


Fig. 26

necessary to have two kinds of coils. By doing this, only half the number of coils are required and room is saved in the slots. The coils are inserted into open slots which are closed by a magnetic wedge. The coil of the regulating winding is lighter than the one of the primary winding, and a slight bend has been added to each end of the lower straight part of the primary coil in order to make room for the upper half of the next primary coil.

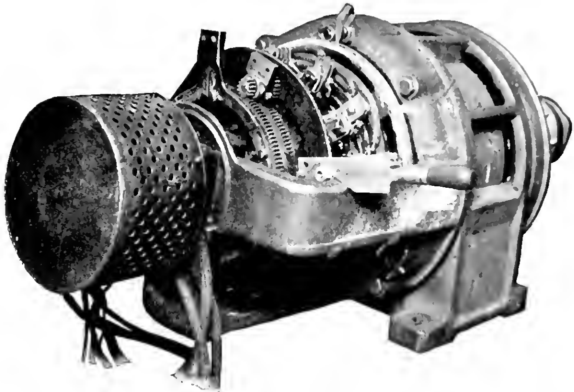


Fig. 27

A 60-slot armature is particularly suitable for this type of winding, as it can be wound with 2, 4, 6, 8, 10, and 12 poles. It is possible to use the same commutator and brush rigging for motors having 4, 6, 8, and 12 poles, by building the secondary with 6, 4, 3, and 2 phases, respectively. This leads to a reduction in the number of required mechanical parts for motors of different frequencies and speeds, which is very advantageous from a manufacturing point of view, and will make this type of motor less costly as soon as there is a sufficient demand for it.

The Keystone Steel and Wire Company

A STEEL PLANT OF THE MIDDLE WEST

By F. B. Crosby

Power and Mining Engineering Department, General Electric Company

It is somewhat of a coincidence that the development of the electrical industry and the growth of the Keystone Steel and Wire Company have occupied practically the same period. The following article first briefly narrates the history of the Company, and then names the factors which led to the location of the plant at its present place. The layout of the plant is illustrated by diagrams. The remainder of the article is devoted to a description of the process of manufacturing steel wire, starting from the raw materials with which the open-hearth furnaces are charged, and ending with the finished product. Interspersed between the sections describing the process are others descriptive of the electric equipment which vitally contributes to the successful operation of the plant.—Editor.

There are perhaps few greater rewards for human endeavor than the satisfaction of watching the continuous evolution, from a simple abstract idea, of a great industry affording livelihood for thousands of individuals and reaching in tangible form to the far corners of the earth.

Such satisfaction must have long since come to Mr. Peter Sommer who, twenty-nine years ago, conceived and embodied in concrete form the idea of weaving from wire a new kind of fence.

The first plant, page 343, was located approximately six miles south of Tremont, Illinois. From this simple beginning the present extensive manufacturing facilities were developed to carry the raw materials, including ore, scrap, and other necessary ingredients, through the elaborate processes, from the open hearth where they are transformed into high-grade steel, to the blooming mill where the massive ingots are reduced to billets; to the rod mill where the billets become rods the size of a lead pencil at the rate of nearly 50 miles aggregate length per hour; to the wire drawing benches and the galvanizing tanks; and finally to the fabricating department where appears in finished form, woven wire fence in a great variety of ornamental and utilitarian designs, barbed wire, steel gates, nails, staples, and other wire products.

This remarkable growth is still further emphasized by the fact that it has occurred within the practical life of the first fence made at Tremont. One hundred and seventy-five rods of this fence stood twenty-seven years of continuous service out of doors before being replaced, a record which will be rarely equalled by present-day fences.

As business increased, the plant was moved successively to Tremont, then to Peoria, and finally to South Bartonville, five miles distant, where the present wire and fence mills are located. The difficulty of obtaining the necessary quality and quantity of steel rods for wire drawing became greater each year, until finally it was decided to extend the activities of the Company to include the manufacture of rods from their own open hearth furnaces. The proximity of Peoria to the scrap iron market and coal fields, as well as its central location with respect to the Minnesota ore beds and the Birmingham pig-iron district, make it an ideal location for such a plant. Transportation facilities are excellent. Fourteen railroads have terminals in Peoria, while the Illinois river affords a waterway, the value of which has already been demonstrated.

The general layout of the South Bartonville (or as it will be called, the Steeldale Plant) is shown in Fig. 1. A plot of 640 acres one mile from the Illinois River and about 1500 feet from the wire mills, together with a 75-foot right-of-way between the two, was acquired, and ground was broken for the steel plant in July 1916. A narrow gauge electric railway runs over this right-of-way and transports the bundled rods from the steel plant to the wire mills. Direct current for these little locomotives is supplied from a 25-kw. induction motor-generator, located in the motor room of the rod mill. The average elevation of the new site rendered advisable the construction of a dike along the river side of the plant as protection against extreme high water.

It is evident from an examination of Fig. 1, that one of the first principles of economic production has been observed in the layout of this plant, namely, straight-line movement of the materials from the stock yards to the finishing mills.

Mention has been made of the Illinois River as a waterway. In order to take advantage of this facility, a canal (Fig. 2) one mile long, 100 feet wide and 12 feet deep was excavated by the Keystone Steel & Wire Company from the steel plant to the river. This canal was utilized in the transportation of the immense quantities of gravel necessary for the new construction. Later a river steamer and barges were chartered to bring pig-iron from the southern furnaces, a distance of approximately 680 miles, traversing in part the Tennessee, Ohio, Mississippi, and Illinois rivers, and finally reaching the Company's docks through their own canal. Much interest is being taken at the present time throughout the Illinois River valley in a possible waterway to the Great Lakes. If favorable action is taken by the State Legislature, the importance of water transportation to the Keystone Steel and Wire Company cannot be overestimated.

The pig iron brought from Birmingham is transferred from barges to flat cars by electromagnets and then to the stock yards. A pile of scrap iron in the stock yard and a gantry crane with a 70-ft. span and a 25-ft. cantilever on each end, which handles both scrap and pig iron, is shown in Fig. 3. The storage area under the main span is 70 ft. by 800 ft., while approximately four times this area is served by locomotive cranes. Plans and specifications for the steel plant were drawn by Julian Kennedy. Briefly, it comprises, in addition to the stock yards, an open hearth building 156 ft. by 308 ft., laid out for extension toward the soaking pit building, which is 82 ft. by 240 ft., and which in turn will be extended toward the open hearth as additional capacity is required. The blooming mill building is 80 ft. by 299 ft., the billet storage 80 ft. by 280 ft., and

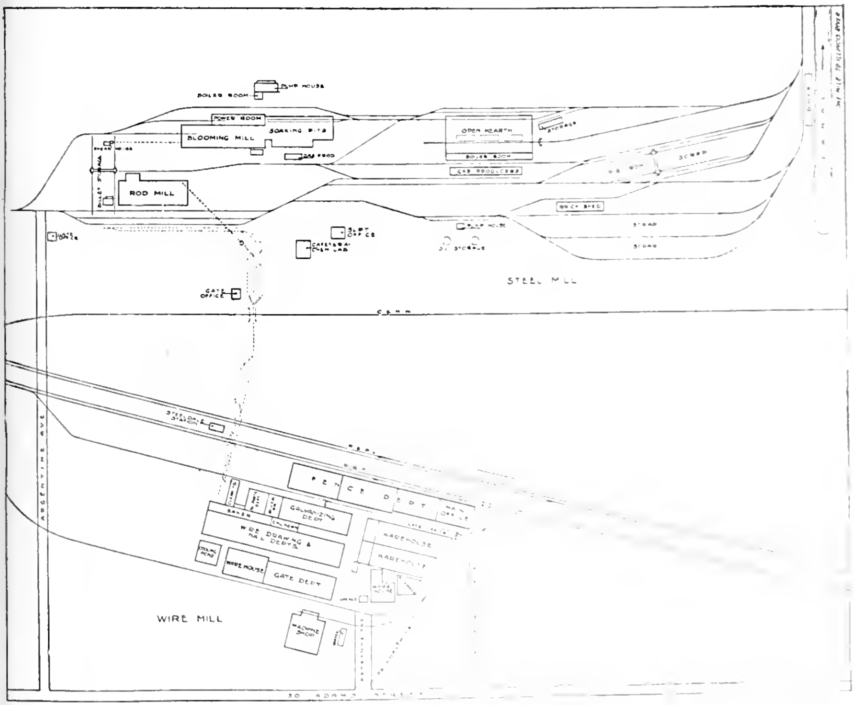


Fig. 1. General Plan of Fabricating and Steel Plants

Fig. 2 Canal, 100 ft. Wide and 12 ft. Deep Extending to the Illinois River One Mile Distant

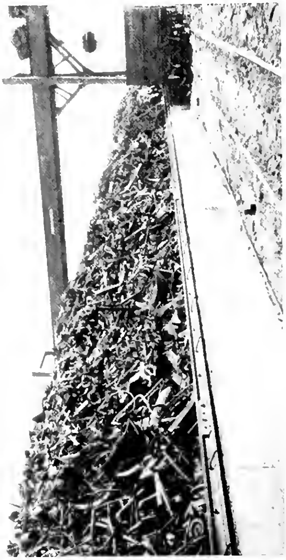


Fig. 3. Scrap Stockyard and 10-ton Gantry Crane with Electric Lifting Magnets

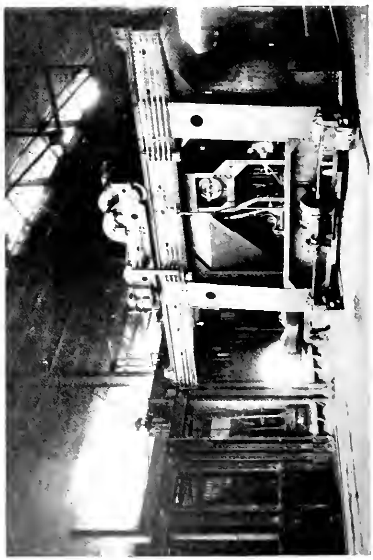


Fig. 4. Alliance High-type Charging Machine in Open Hearth Dept.

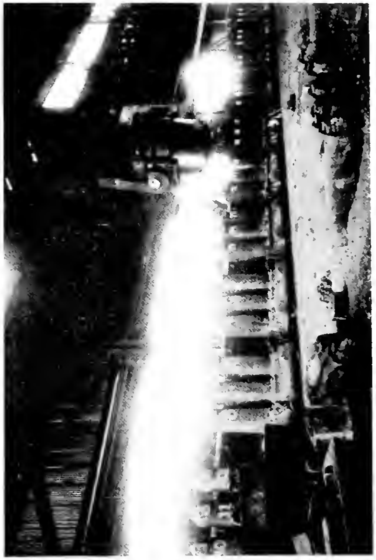


Fig. 5. Pouring side of Open Hearth, showing 125-ton Ladle Crane Filling Ingot Molds

Fig. 6. Ingot Stripper Crane Stripping Ingots in Soaking Pit Building

Fig. 7. Soaking Pit Crane Removing Ingo from Pit for Transporting to Blooming Mill

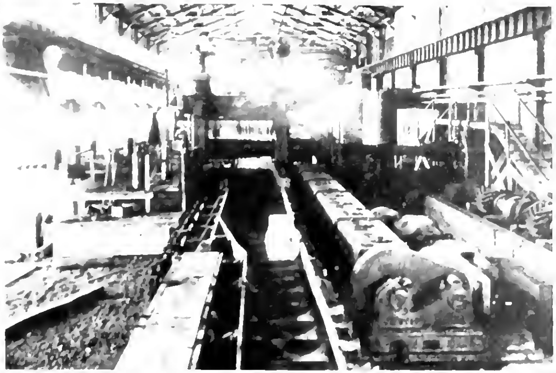


Fig. 8. General View of [illegible]-in. Reversing Blooming Mill Looking from the Soaking Pit Showing Approach Table Motors at the Right and Repeater at the Left

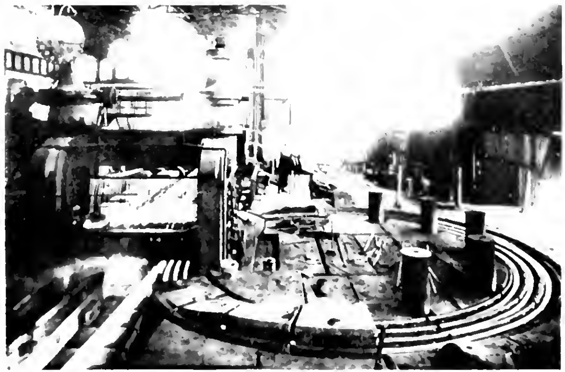


Fig. 9. "Close Up" of Blooming Mill and Repeater Looking Toward the Soaking Pit Building

the rod mill 83 ft. by 225 ft. The gas producers for the rod mill, open hearth furnace, and the soaking pit building are housed in lean-to's adjacent to each other. The pump house contains both motor- and turbo-driven pumps, with auxiliary coal fired boilers for the steam pumps in case of failure of the steam supply from the waste heat boilers that are installed in connection with the gas producers.

The variety of materials used in the manufacture of open hearth steel is seldom appreciated by those not actively engaged in the industry.

Limestone is the first ingredient charged in the open hearth; this is followed by *scrap iron* and steel, which in turn are supplemented by *pig iron*, or in some cases by hot metal direct from the blast furnace. As the charge melts the limestone liquefies and, rising to the top of the bath, forms a slag which to a great extent absorbs the sulphur, phosphorus, silicon, and other impurities.

Fluor Spar is used as a flux for thinning the slag formed by the limestone and impurities mentioned above.

Iron Ore usually in the form of an oxide is added to decarbonize the metal.

Ferro Manganese is added in the ladle for two reasons, 1st, to deoxidize the metal; and 2nd, to increase the manganese content, which to a great extent determines the characteristics of the steel for rolling and drawing.

Aluminum thrown into the ingot mold during pouring has a tendency to quiet the molten metal and prevent it from boiling over the top of the mold.

The intense heat to which the open hearths are subjected is naturally very destructive to the linings, the character of which determines to a great extent the quality of the finished steel. The bottom and sides must be repaired after each heat in order to protect the expensive magnesite brick lining. Among the materials used for this purpose are dolomite, magnesite, magnite, kendymag, and chrome ore, the last being used chiefly for the walls and sides of the furnaces above the slag line.

Fig. 4 shows a 5-ton Alliance high-type charging machine in the open hearth building. Three furnaces are in operation, two of which are fired with producer gas and the third with crude oil. The furnaces are rated at 75 tons but will hold 90 tons, and will average at least two heats per day of 24 hours. Provision is made for three more furnaces as soon as required. The gas producers are hand poked with the usual arrangement of crusher, over-head bins, and lorry cars to provide a 36-hour coal supply. Waste heat boilers provide steam for the turbo-driven pumps and miscellaneous use about the plant.

Fig 5 shows the pouring from a standard four-girder 125-ton Alliance ladle crane with 40-ton auxiliary hoist on its own girders. The pouring platform of the open hearth is 12 ft. by 175 ft., and the general layout of the plant is such as to permit a straight run to the stripper and soaking pit building. The 100-ton stripper crane with a 78-ft. span and the 5-ton soaking pit crane with an 18-ft. lift were both built by the Alliance Machine Company.

Figs. 6 and 7 show these cranes in operation. The soaking pit covers are removed by hydraulic cylinders, which move them up an inclined support. They are re-seated by gravity. The pit crane deposits the ingot directly on the approach table of the blooming mill so that no ingot buggy is required.

The 35-in. reversing blooming mill shown in Fig. 8 was entirely built by the Wheeling Mold & Foundry Company, of Wheeling, W. Va., to roll an 18- by 20-in. ingot down to $1\frac{3}{4}$-in. square billet on one set of rolls. This is accomplished by repeating the last four passes, i.e., by looping the roll housing in a complete circle as shown in Fig. 9. The overfeed loops onto the floor and moves in a direct line parallel with the center line of the mill, beyond the building columns. As the piece enters the repeater after the last pass it is depressed below the repeater floor and carried by a continuous conveyor to the shear house, a distance of 450 feet, where it is sheared to 30-foot lengths for the rod mill.

The balanced weights for the top roll of the mill are of unique design. Due to the shallowness of the pit under the mill, solid castings are used instead of the customary levers with quadrant and counter-balance weight.

On the run-out side of the blooming mill there are two hydraulic shears located 102 ft. 4 in. from center to center. These shears are used to crop the ends of the bloom before it enters the repeating passes. During the last four passes in the repeater the mill rolls are held in one position at a fixed distance center to center.

The manipulator is a modified Kennedy-Wellman type, the fingers of which move

Fig. 11 Another View of the 2500 h.p. Reversing Motor and the 2000-kw. Flywheel Motor-generator with 110,000 lb Flywheel

Fig. 13 General View of Side Guards and Manipulator Drives

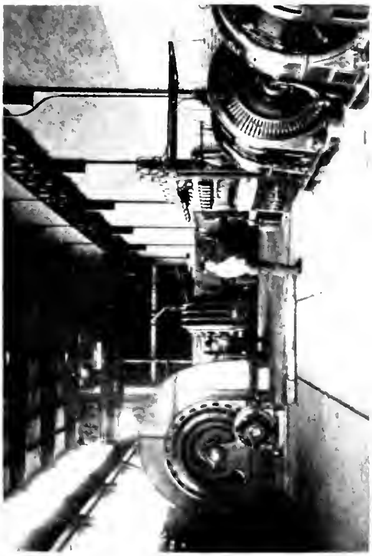


Fig. 10 General View of Blooming Mill Motor Room showing Reversing Motor, Flywheel Motor generator, and Synchronous Motor generators for Direct-current Auxiliaries

Fig. 12 Motor Exciter, Slip Regulator, and Control Panel for Starting the Flywheel Motor generator, Fig. 11

simultaneously with the guards. The manipulator fingers are operated by means of a square shaft under the pushing bars, this shaft actuates the fingers, and performs the tilting operation by means of a lever and crank shaft.

The mill is also arranged for rolling commercial billets or blooms; consequently, at the end of the last shear a conveyor is provided to take care of this product.

While in general the drive (Figs. 10 and 11) for this mill is similar to all modern reversing equipments, in that the well-known Ward-Leonard field control and equalization of demand by suitable a-c.-d-c. flywheel motor-generator are employed, certain modifications in design and arrangement introduced by the General Electric Company have successfully demonstrated its superiority as compared with earlier installations. The main motor, built in a single unit, is the largest capacity single-unit reversing-motor in this country, with the exception of an exact duplicate installed by the Ashland Iron & Mining Co.

Three-phase, 60-cycle power is purchased from the local power company at 2300 volts for driving the flywheel induction motor-generator. The induction motor is rated 2000 h.p. at 360 r.p.m., 2300 volts, and the generator 2000 kw. at 360 r.p.m., 500 volts. The flywheel weighs 110,000 pounds. The liquid slip regulator (Fig. 12) in the secondary circuit of the induction motor provides for an automatic retardation and acceleration of the flywheel, thus enabling it to absorb the peak demand of the mill during successive passes. Contrary to general practice heretofore, complete current limit automatic magnetic control for starting and plugging the flywheel set from the master controller is provided. This arrangement, while considerably more expensive than the customary use of a slip regulator for starting and slip regulation, permits, by the movement of a single master controller, normal starting and stopping; or, in emergency, will bring the set to rest in 4 or 5 minutes instead of several hours as would be required under the influence of friction and windage only.

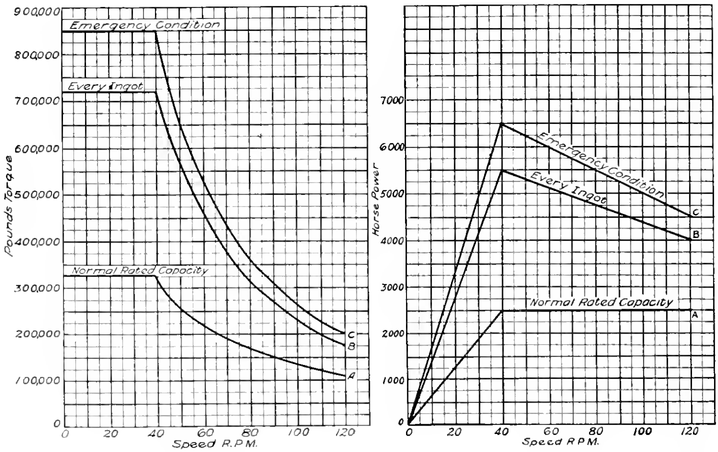


Fig. 14. Guaranteed Speed Horse Power and Speed Torque Curves for Reversing Blooming Mill Drive

The main roll motor has a guaranteed continuous rating of 2500 h.p., from 40 to 120 r.p.m., with a temperature rise not to exceed 50 deg. C. Curves showing guaranteed values of torque, and horse power for (a), continuous load; (b), continuously recurring cycle; and (c), emergency conditions are shown in Fig. 14. The question of maxi-

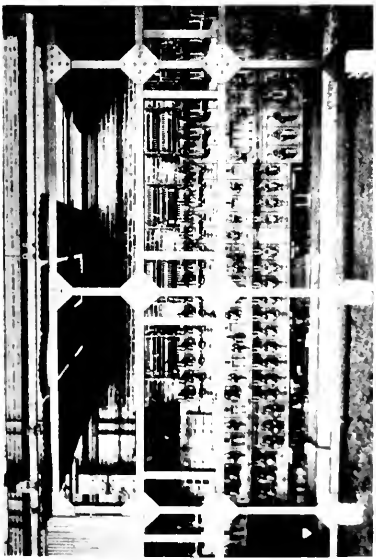


Fig. 15. Contactor Panels for Screw-down, Manipulator, and Side Guards

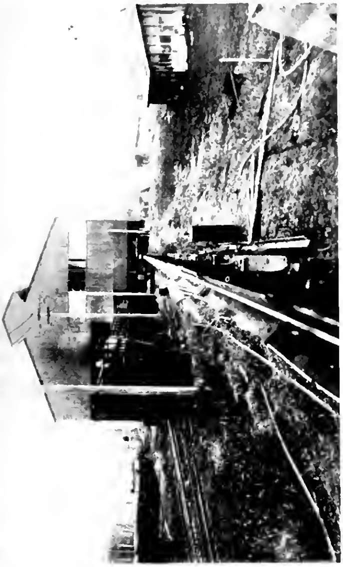


Fig. 16. Loading Conveyor for Commercial Billets, also Conveyor for Rod Mill Billets

Fig. 17. Shear House and Cooling Bed for Rod Mill Billets

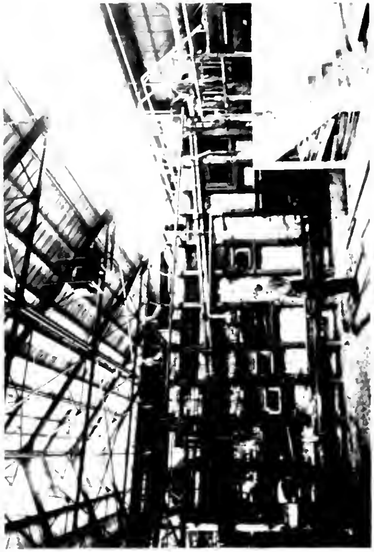


Fig. 18. Charging Side of Reheating Furnace in Rod Mill

mum momentary rating is simply one of commutation, and in factory test and under actual operating conditions since installation it has been conclusively shown that the maximum momentary guaranteed values of torque and horse power as given in these curves were very conservative. While the guaranteed emergency torque was but 850,000 pounds at 1 foot radius from 0 to 40 r.p.m., the motor has actually developed 1,100,000 pounds.

In spite of its tremendous power and massive construction the acceleration characteristics are excellent. Complete reversal from 120 r.p.m. forward to 120 r.p.m. reverse can be obtained in approximately 5½ seconds, or from 50 r.p.m. forward to 50 r.p.m. reverse in 2 seconds. The rotor can be rocked in its bearings backward and forward through an arc of 10 to 15 deg. as rapidly as the master controller can be moved, or from 50 to 60 times per minute.

The remarkable speed characteristic is largely due to the use of a fully compensated shunt motor and the elimination of the compounding which, previous to this installation, had been in general use. Compounding, while affording considerable protection to the motor, of necessity gives a drooping speed characteristic and consequently a sluggish drive as compared with a simple shunt machine. The use of the shunt-wound motor further simplifies the equipment by the elimination of the series-compounding exciter as well as the series field on the motor itself.

Because of the intermittent character of the load, low average speed, and idle intervals, forced ventilation is supplied, with provision for washing and humidifying the air before it enters the motor.

Figs. 13 and 15 show typical installations of mill type motors for operating side guards and manipulators, and also typical magnetic control panels for auxiliary motors, all of which were furnished by the General Electric Company.

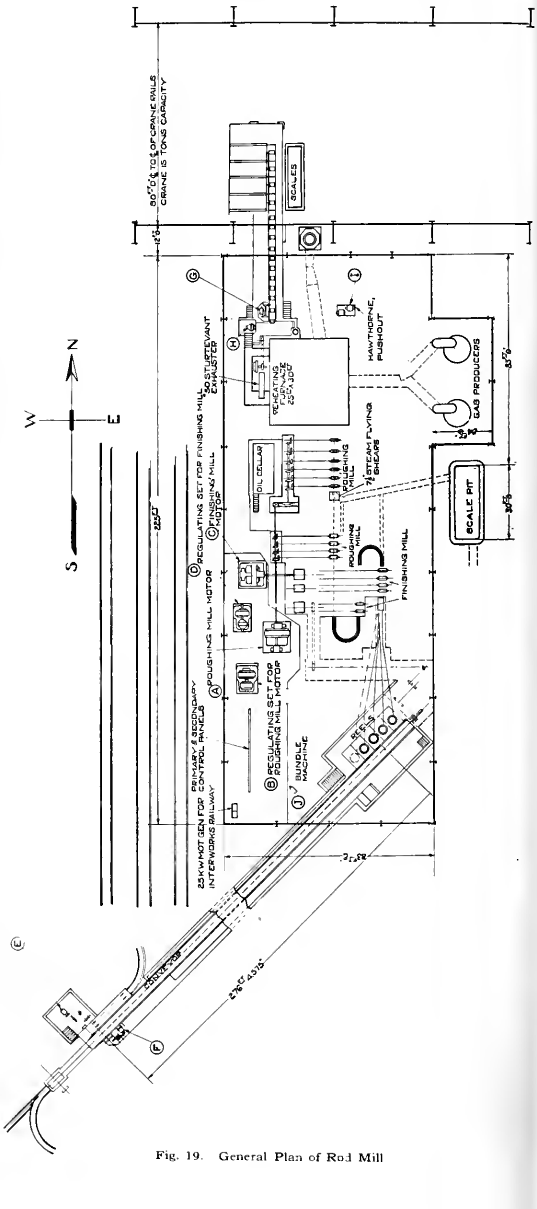


Fig. 19. General Plan of Rod Mill

Fig. 16 shows the 450-ft., $1\frac{3}{4}$-in. square billet on the way from the repeater of Fig. 9 to the shear house, where it is cut up into 30-foot lengths weighing 300 pounds each. The sheared billets, Fig. 17, are stored between the shear house and the rod mill, as shown in Fig. 1. From here they are carried, as needed, to the rod mill by an overhead yard crane.

The general layout of the rod mill is shown in Fig. 19.

The billets are placed in the conveyor and charged cold in the re-heating furnace, which has a capacity of 195 billets 30 feet long and $1\frac{3}{4}$ inches square. The mill and furnace are so proportioned that at the maximum rate of production the billets attain a uniform temperature during their continuous passage through the furnace. Upon arrival at the lower end of the inclined hearth a motor-driven ram, shown in the lower left-hand corner of Fig. 20, shoves the billet into the roughing mill, Fig. 21. Two rods are in this mill simultaneously. The entire mill consists of 16 stands, 10 roughing, and 6 finishing stands. An Edwards flying shear crops the ends of the billets between the 6th and 7th stands; repeaters are placed between the 10th and 11th and the 12th and 13th stands. As the rods are looped simultaneously in two groups of stands driven by independent motors, a means of nice adjustment of length of loop is provided, which will be described below. As the rods leave the finishing stand in sizes ranging from No. 5 to $\frac{3}{4}$-inch diameter, they pass to vertical reeling machines of the pouring type which run in exact synchronism with the finishing stands, and at speeds determined by the size of rod being rolled. These reels will take up No. 5 rods at the rate of 2600 feet per minute. Four reels are provided, two of which are receiving the rods while the other two are pouring. The bundles of rods may be varied from 26 in. by 36 in. to 34 in. by 44 in. in diameter.

The double stand, continuous repeating mill with suspended-roof, inclined hearth, re-heating furnace, gas producers, reeling machines, and muffle-conveyor were all built by the Morgan Construction Company of Worcester, Mass.

The bundles are "poured" onto a muffle type air-tight water-cooled conveyor, approximately 250 feet in length, which insures perfect annealing with minimum oxidization, and carried to the scale house for weighing before transportation to the wire mill.

Mention has been made of the fact that the rod mill is driven by two independent motors. The ten roughing stands in tandem are driven by a three-phase, 60-cycle, 2300-volt induction motor rated 2360 h.p. at 410 r.p.m. and designed to operate at constant torque with a double-range speed regulating set of the modified Scherbius type, from 410 r.p.m. down to 250 r.p.m. The six finishing stands, arranged in two groups of two and four, respectively, are driven by a similar motor rated 1180 h.p. at 560 r.p.m., and designed to operate at constant torque with a similar speed regulating set from 560 r.p.m. to 336 r.p.m. Since under normal conditions there are always rods looped simultaneously in the roughing and finishing trains, it is absolutely essential that the motors driving the mill should each be capable of rapid and exact speed adjustment in order to prevent the possibility of excessive looping or stretching of the rod, as would be the case if the pitch velocity of the adjacent roughing and finishing rolls differed appreciably. The wide range of speeds is required to take care of a variety of product from No. 5 to $\frac{3}{4}$-inch rods.

Figs. 21 and 22 show the main motors, speed regulating sets, and primary and secondary control panels, all of which were furnished by the General Electric Company.

The modified double range Scherbius system of speed control for induction motors is specially advantageous where accurate speed adjustment, high efficiency and power factor, and high maximum torque are important considerations.

This system makes use of a two-unit motor-generator whose functions are reversible. One unit is a compensated polyphase commutator machine which, when the main motor runs below synchronism, operates as a motor to drive the second unit, which is a squirrel-cage induction motor, slightly above its synchronous speed, causing it to function as an asynchronous induction-generator, returning to the power system the secondary energy of the main motor less, of course, the losses incurred in the double transformation. When the main motor operates above synchronism, the squirrel-cage unit functions as a normal induction motor driving the commutator machine as a generator so that energy is taken from the power system and fed into the rotor as well as the stator of the main motor.

With the regulating set in service, the normal synchronous speed point of the main motor absolutely disappears and the maximum running torque is available at and near

Fig. 20. Roughing Stands and Discharge Side of Reheating Furnace in Rod Mill

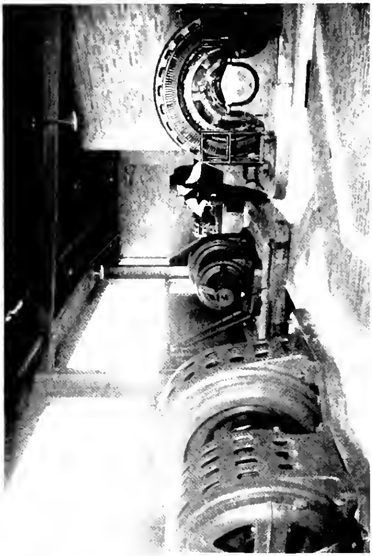


Fig. 21. Motor Room in Rod Mill, Showing the 2360-h.p. Roughing Motor, the 1180-h.p. Finishing Motor and Their Respective Speed Regulating Sets

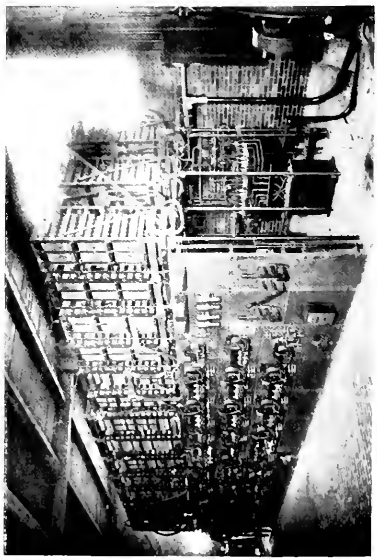


Fig. 22. Primary and Secondary Control Panels for Rod Mill Motors

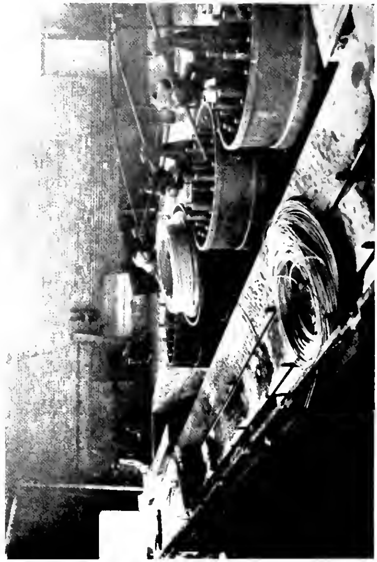


Fig. 23. Edwards Pouring Reels and Bundle Conveyor in Rod Mill

synchronism, as well as at points remote therefrom. Without entering upon a detailed explanation of the system, attention is merely directed to, *first*, the fact that the speed-torque curves for any induction motor are similar above and below synchronism; and *second*, to the fact that in any electrical circuit a counter e.m.f. may be substituted for an ohmic resistance. By varying the excitation of the commutator machine a counter e.m.f. of proper voltage, frequency, and phase rotation is impressed on the collector rings of the main motor; consequently, the speed of the main motor must correspond to these impressed values.

With the regulating set idle the main motor functions as a simple induction motor. When rolling No. 5 rod from $1\frac{3}{4}$-inch billets it has been found possible to cut out the auxiliary set for the roughing mill motor which thus operates as an ordinary constant speed machine near synchronism. The proper length of loop and delivery speed is obtained by manipulating the speed of the finishing mill motor only with its auxiliary speed regulating set.

Practically all electric power used at present is purchased from the local central station system. The Company has, however, installed a 500 kw., 2300-volt, 60-cycle turbo-generator and two 500 kw. synchronous motor-generators, all built by the General Electric Company for supplying auxiliary direct-current motors on cranes and mill tables, etc.

It is of more than passing interest to note that with all the pressure of development and construction of a complete new steel plant, the Keystone Steel & Wire Company has kept in mind the welfare of its employees. A considerable number of hollow tile houses have been built in desirable locations, within walking distance of the plant, and more will follow. A cafeteria, with seating capacity for 100, where well-prepared meals at cost or less can be had any hour of the day, is very popular. Sanitation and first-aid facilities have received particular attention.

Original Plant of Keystone Steel and Wire Co.

The Value of "g" in Engineering and Physical Work

By Sanford A. Moss

Turbine Department, Lynn Works, General Electric Company

The effect of variations in the intensity of gravity is very often discussed, but the exact magnitude of the effect, and the complete method of taking account of it, is never given except in inaccessible treatises on Geodesy. Dr. Moss has collected the data on the matter and arranged it in convenient shape so that the exact magnitude of the variation is easily seen, and the cases where corrections are necessary are easily found. The data for making the corrections when they are necessary are also worked up in a form which is very much more convenient for actual use than has ever been given before. It is proposed that each laboratory work up, once for all, its correction factor for reducing force measurements, etc., to the standard "g" from the data which is given, and thereafter use the factor in experimental work, or not, according to the degree of precision desired.—Editor.

The author has had the privilege, while writing the article, of collaborating with the Coast and Geodetic Survey officials and with Professor E. V. Huntington, Associate Professor of Mathematics at Harvard, who is a recognized authority on the subject. The data given may, therefore, be considered authoritative.

Introduction

The acceleration of gravity, called *g*, which is about 981 cm. per second per second or about 32 feet per second per second, often occurs in engineering computation. In many physical and engineering measurements and formulæ, some of which are listed later, the proper numerical value of *g* must be used. It is well known that *g* varies very slightly from place to place on the earth's surface. The exact values will be here discussed from the point of view of the engineer and physicist. Corrections to take account of the variations, which vary from about a quarter of a per cent to a few thousandths of a per cent, are arrived at. For many purposes, such corrections are negligible and such are pointed out. The precise work where corrections are necessary is also pointed out, and exact correction data are given in convenient shape.

The measurements to be corrected depend upon the attraction of the earth upon a weight, often measured by the acceleration which it will give to any weight. For instance, pressures are measured in lbs./sq. in., which originally meant that there is a force on a square inch equal to the attraction of the earth on a certain standard weight defined as the "standard pound weight." It would not do to have units such as this vary from place to place with the attraction of gravity, so by recent universal consent in all such cases the force unit is taken as that giving the standard pound weight a particular acceleration, 980.665 cm./sec.^{2}

Standard Value of "*g*"

The value of *g* at any locality is measured by the acceleration of any freely falling body.*

It was early recognized that even though the variation from place to place was small, it was desirable for many reasons to fix upon a standard reference value.

For many years this was specified as being that at sea level, 45 degrees north latitude. As will be seen later, this is not an accurate specification, as the acceleration of gravity at sea level is somewhat different at different places on the circle of 45 degrees north latitude. Furthermore, the value which was originally assigned to the average at sea level 45 degrees north latitude has been shown by later measurements to be somewhat inaccurate. Hence, it is now universally agreed† that g_0, the standard value of the acceleration of gravity, is 980.665 cm. per second per second, or 32.1740 feet per second per second. This is the standard value until it is changed by international agreement, regardless as to whether it is the exact average value at sea level 45 deg. N. Lat. It was supposed to be this at the time of adoption, but the latest work of the Coast and Geodetic Survey gives 980.621.‡

Of course the exact average value at sea level 45 deg. N. Lat. will be changed slightly by each large addition of new data, but this will not affect the arbitrary standard value.

Accurate Local Values of *g*

Geodetic Bureaus of the governments of the United States and of many other countries have spent a great deal of time on measurements of the actual values of gravity at various points on the earth's surface and have established formulæ and theories regarding it.

* *g* is defined as "falling acceleration" by Prof. E. V. Huntington, Am. Math. Mo., Vol. 24, page 6, Jan. 1917.

† Proces-Verbaux des Séances, Comité International des Poids et Mesures, page 172, 1901.

Bureau of Standards, Circular No. 34, 3rd Ed. 1915, Relation of H.P. to KW., page 6.

‡ Page 134, Pub. No. 40, by Wm. Bowie.

In the United States this work has been done by the United States Coast and Geodetic Survey, E. Lester Jones, present superintendent, and many exhaustive reports have been published.*

A rational formula can, of course, be deduced for the value of the acceleration of gravity for any latitude on a perfect ellipsoid of uniform density, and this gives the first approximation to the value of g at sea level. A simple rational formula called the "free air correction" can also be deduced for the effect of elevation above sea level, if we assume that we are located in free air at a distance above sea level without any intervening earth. The effect on the value of gravity at any point of actual earth between sea level and a given elevation; the effect of varying density of different geologic strata immediately under the point; the effect of plateaus, mountains, and sea depressions at a distance from the given point, etc., all make a very complicated problem.

It has been found that this problem is somewhat simplified by what is called isostatic adjustment. If the earth were a perfect fluid, but composed of materials of different density, there would be flow and adjustments of the different materials so as to give bulges or plateaus in regions where density was less than average, and depressions or oceans in regions where density was greater than average. The earth is not nearly a perfect fluid, however, and this isostatic adjustment is not at all complete. The theory of this matter of isostasy cannot be discussed here. It will be sufficient to state that it gives a rational correction to the simple formulæ mentioned above. In the present state of the subject, even this correction, called isostatic compensation, does not quite give the actually observed values of gravity. The departure of an observed value from a computed value is called an anomaly. The Coast and Geodetic Survey publications above mentioned give complete details for computation by several different methods of corrections to the formulæ given, together with the anomaly for 219 gravity stations in the United States and many in other parts of the world.†

Actual Values of g in the United States

The rational computations are quite complicated, and even when they are made, in order to get accurate results, the anomalies must be taken into account. For our purposes, we need only the values of gravity at given points computed by the most direct methods, regardless of rational theory. We will, therefore, use values computed by a general formula corrected for elevation, and group all of the other corrections together as an anomaly which is to be obtained from a map.

There are two methods suitable for doing this, both starting with the Helmert 1901 formula for g_o,‡ which is, in centimeters per second per second, for latitude φ, at sea level

$$g_o = 978.030\ (1 + 0.005302\ \sin^2 \varphi - 0.000007\ \sin^2 2\varphi) \qquad (1)$$

The Bouguer method, often employed, uses a correction for elevation which comes out $-0.000210\ H$ to $-0.000192\ H$, while the "free air" method uses the correction $-0.0003086\ H$ (H in meters). Both methods, of course, give the same results if the proper anomaly is used. However, the anomaly is small in either case and is frequently omitted. Hence, that method is preferable which gives the smaller average anomaly. This will be found to be the "Free Air Method"§ which gives as the elevation correction to g in cm. sec.^{2}, $-0.0003086\ H$ or $-0.00009406\ H_f$, where H_f is in feet.

The Bouguer formula gives as a mean value for the latter constant, the much lower value -0.0000588. This is traditionally used as the proper elevation correction, but the data here given show that it is inaccurate.

Hence, the method to be used for finding the actual value of the correction factor (explained in the next paragraph) to reduce to the standard value of g, 980.665 cm. sec.^{2} or 32.1740 ft. sec.^{2}, is to use values for the given latitude, as Table 1, corrected for elevation as Table 2, and if great accuracy is desired, further corrected for anomaly, as by the map, Fig. 1. The complete methods are exemplified

* 1. Figure of the Earth and Isostasy from Measurements in the United States, by J. F. Hayford, 1909.

2. Supplementary Investigation in 1909 of the Figure of the Earth and Isostasy, by J. F. Hayford, 1910.

3. Effect of Topography and Isostatic Compensation upon the Intensity of Gravity, by J. F. Hayford and William Bowie (Special Publication No. 10), 1912.

4. Same title, second paper, by William Bowie (Special Publication No. 12), 1912.

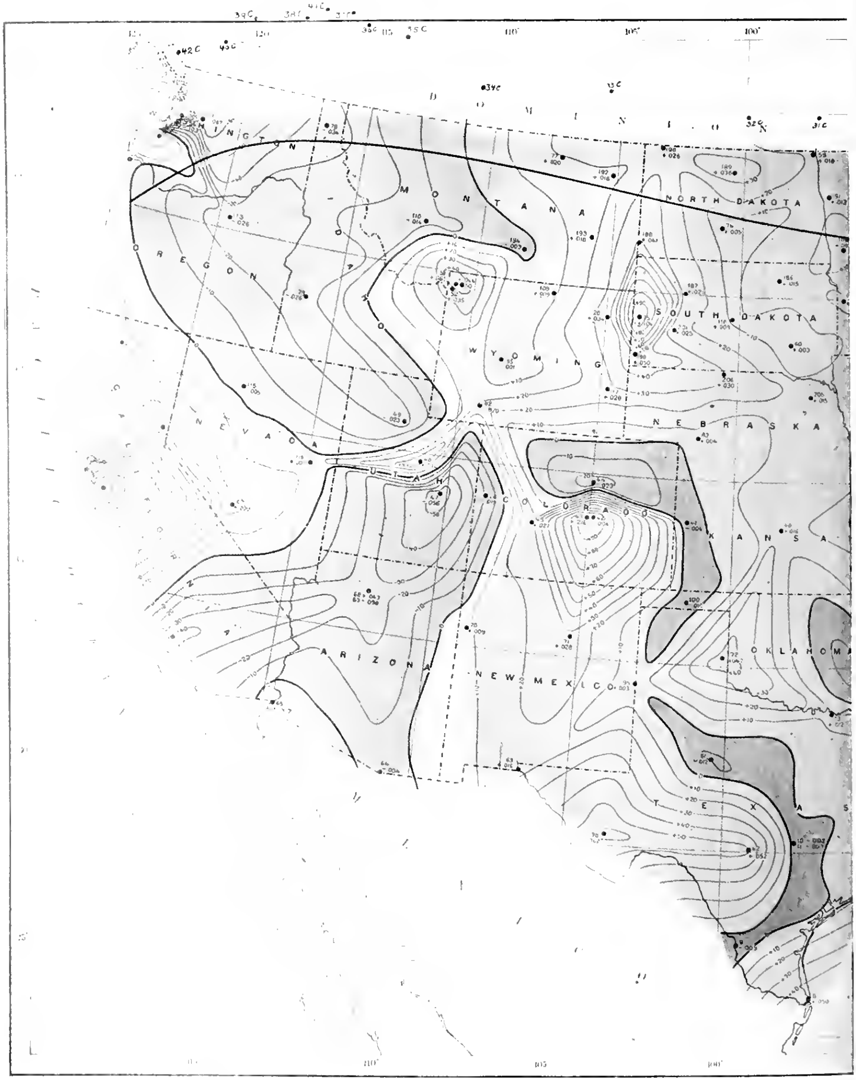
5. Investigations of Gravity and Isostasy, by William Bowie (Special Publication No. 40), 1917.

Résumé of all this work is given in special Publication No. 40, from which much of the following data are obtained. The writer is also indebted to Messrs. E. Lester Jones, A. A. Brooks, W. W. Johnson, R. L. Faris, Dr. H. N. Davis, and Prof. E. V. Huntington, for assistance in preparing this article.

† See the Appendix for details.

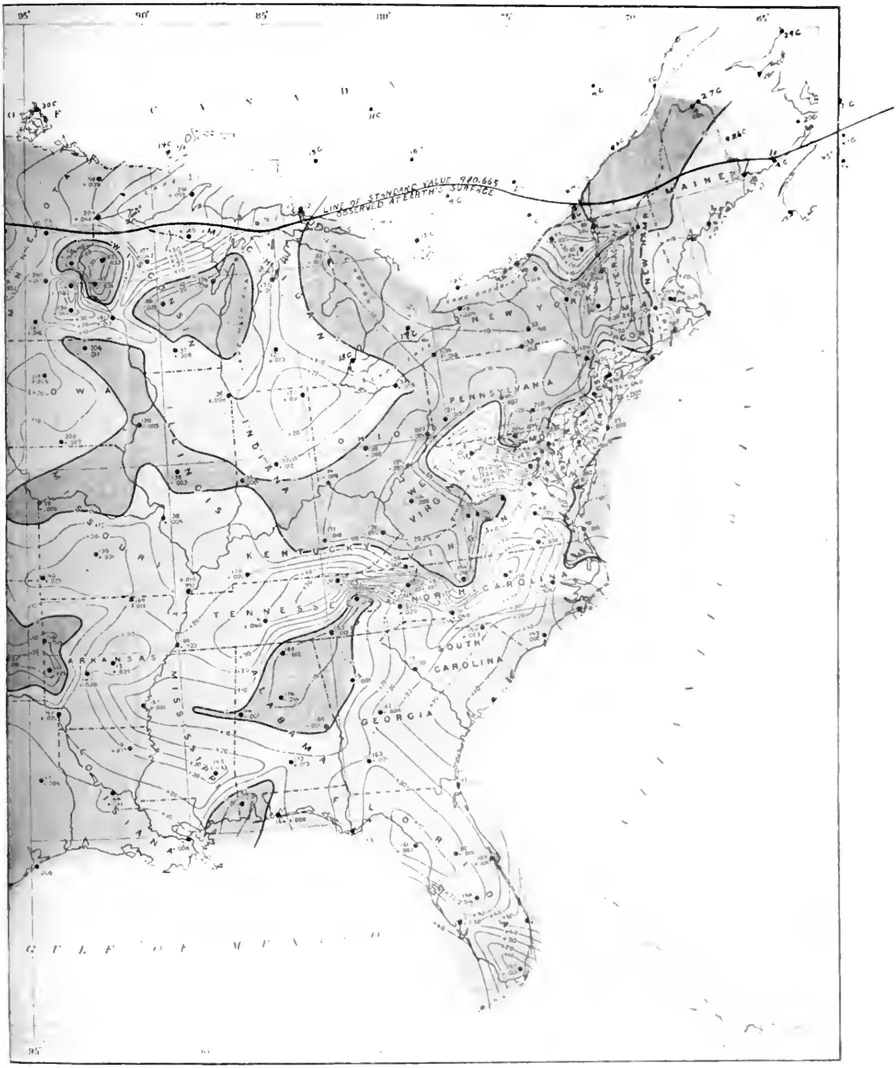
‡ This is given on page 12 of publication No. 10 and page 49 of publication No. 40.

§ This is shown by inspection of Figs. 13 and 14 of publication No. 40. The latter is by the "Free Air Method" and is the map reproduced in this article, and gives anomalies varying from −0.050 to +0.120. The former is by the Bouguer method and gives anomalies varying from −0.220 to +0.040. There are large negative values in mountainous regions, showing that the constant is numerically too small.



MAP OF ANOMALIES FOR "FREE AIR CORRECTION."

Fig. 1. Map of Anomalies for "Free Air Correction." The values of anomalies given along each "line of equal anomaly" are to be added to the third decimal place of the computed value of g in cm sec.^{2} in addition to the corrections for latitude and elevation. The values given along each line, divided by 1,000,000 (exactly 980,665) give the correction factor which is to be multiplied by the measurement of a force by



a weight scales and added to the reading. The correction is everywhere less than one one-hundredth of a per cent, except near Pikes Peak, Lead, S. Dak., and Mt. Hamilton, Cal., and is therefore negligible for most purposes. The various black dots are gravity stations of the U. S. Coast and Geodetic Survey, and the values alongside them are the anomalies at the stations and form the basis of the lines of equal anomaly. This map is a copy of Fig. 14, Spec. Pub. No. 40. The line slightly above 45 deg. N Lat. where g has the standard value, was added by the writer.

in Tables 3 and 5. Each laboratory should make such a computation.

The correction for latitude has a maximum value of about fourteen-hundredths of one per cent (in the southernmost part of the United States).

The correction for elevation comes out about one one-hundredth of one per cent per one thousand feet elevation.

The anomaly read from the gravity contours on the map, Fig. 1, comes out as a maximum about one one-hundredth of one per cent around Pikes Peak, Lead, South Dakota, and Mt. Hamilton, California, and never reaches more than about one-half of this value elsewhere, so that the map need not be used for engineering purposes, but only for precise physical work.

Reduction of Forces to Standard Values

In all cases (samples of which are given in the next paragraphs) when a force of a pound (or gram) is used it is understood to be the "standard pound force."* This is a force giving the standard weight of 1 lb. (or gram) an acceleration of the standard value, $g_o = 980.665$. Gravity has this value at the earth's surface along a line given on the upper part of Fig. 1.

A "local pound force" is a force which would give the standard pound weight an acceleration equal to the local acceleration of gravity.

Whenever we measure forces by means of instruments which depend upon the attraction of gravity, we measure in local pounds and must reduce to standard pounds by using the correction factors given beyond. Examples are as follows:

Platform scales or other scales with weights, used to measure power by means of a brake such as a Prony brake, electric dynamometer, or a water brake.

Platform scales, etc., used to measure fluid velocity by means of nozzle reaction.

Dead weight gauges which measure pressure in lbs./sq in. by means of weighted pistons.

Mercury, water, or other liquid pressure gauges, either with a U with equal legs or with a reservoir and a single leg.

Testing machines used in testing materials.

Experimental thermodynamic measurements, such as measurements of specific heat where some force is measured by the attraction of the earth on a weight. This is usually a pressure measurement, however, covered by the pressure-measuring instruments above.

We may summarize by saying that the corrections given are required in all cases where forces are measured by beam balances or weight scales. The correction would also apply with change of sign in the improbable event that a spring balance was used for precise weighing. The corrections are not to be used for cases of weighing with weight scales nor for cases of force measured with springs which read standard pounds.

* The distinction between standard pound force and local pound force, originally suggested by Prof. E. V. Huntington, (Bull. S. P. E. E., vol. 3, pp. 678-689, June 1913, and Vol. 5, pages 20–22, February 1915), has been adopted by the Bureau of Standards (Bulletin No. 34, 2nd and 3rd editions, 1914 and 1915, page 7)

TABLE 1

CORRECTION FACTOR FOR LATITUDE IN THE UNITED STATES

The correction factor given in the table is

$$-\frac{980.665-978.030}{980.665}$$

$$+\frac{978.030\times0.005302}{980.665}\sin^2\phi$$

$$-\frac{978.030\times0.000007}{980.665}\sin^2 2\phi$$

or

$$0.0052878\sin^2\phi$$
$$-0.0000069812\sin^2 2\phi-0.0026870$$

To correct for latitude we multiply the measurement of a force on a weight scales by the correction factor given, and add it to the reading. (Subtract when correction is negative.)

ϕ N. Latitude	Nearby Principal Places	Correction Factor	Difference
25	Key West, Fla.	−0.001747	
			0.000377
30	New Orleans, La. Austin, Texas. .	−0.001370	
			0.000417
35	Charlotte, N. C. Memphis, Tenn.	−0.000953	
			0.000444
40	Philadelphia, Pa. Denver, Colo. .	−0.000509	
			0.000459
45	Calais, Me. . . . Minneapolis, Minn.	−0.000050	
			0.000459
50	Winnipeg, Canada	+0.000409	

Notation for Correction Factor Formulæ

g = actual value of gravity at any point, cm./sec.^{2}.

g_c = computed value of gravity per equation (1).

g_o = 980.665 cm./sec.^{2} or 32.1740 ft./sec.^{2}. This is the standard value of gravity.

ϕ = latitude.

H_f = elevation in feet.

N = anomaly obtained from Fig. 1. Observed g minus computed g.

Deduction of Correction Factor Formulæ for the United States

As already fully explained

$$g = 978.030\ (1 + 0.005302\ sin^2\ \phi - 0.000007\ sin^2\ 2\ \phi) - 0.00009406\ H_f + N.$$

To obtain the value of a force in standard pounds, we must multiply the value in local pounds as read from a weight scales by the factor g/g_o.
Now

$$g/g_o = 1 + (g - g_o)/g_o$$

Hence we multiply the reading of the weight scales by the factor $(g-g_o)/g_o$ and add the product to the reading.
We have

$$(g-g_o)/g_o = 978.030 \times \frac{0.005302}{980.665} sin^2\ \phi - 978.030 \times \frac{0.000007}{980.665} sin^2\ 2\ \phi + \frac{978.030 - 980.665}{980.665} - \frac{0.00009406}{980.665} H_f + \frac{N}{980.665}$$

This gives the final corrections for latitude and elevation given respectively in Tables 1 and 2 and for the anomaly obtained from Fig. 1.

"g" in Formulæ

The fundamental formula which is the basis of all formulæ where g appears is

$$F = W/a\ g$$

Here F is a force acting on a weight W and producing an acceleration a. Much has been written regarding the technicalities of this formula which it is not our purpose to discuss.

In all our cases we mean by weight the value W_o found by comparing a given body with the piece of metal called the "standard pound weight" by means of a beam balance or weight scales. (This has been called the "standard weight.") As already pointed out we mean by g the arbitrary value g_o. F is force measured in "standard pounds" as already defined. a is acceleration in ft./sec.^{2}. The fundamental equation then is

$$F = W_o\ a/g_o$$

Hence, in all formulæ in which g occurs in connection with the standard units of the preceding paragraph, the value is understood as being g_o, which is 980.665 cm/sec.^{2} or 32.1740 ft./sec.^{2}, regardless of place. A few such formulæ are as follows:

All formulæ of mechanics giving general relations, such as centrifugal force, $W_o r\omega^2/g_o$, kinetic energy, $W_o V^2/2g_o$, momentum, $W_o V/g_o$, forces with respect to moving axes, etc. (This does not include formulæ giving accelerations or forces due to the attraction of the earth at a particular place referred to later.)

Formulæ for flow of steam and gases due to standard pressures.

Formulæ of thermodynamics giving relations between energy in thermal units, such as B.t.u., and mechanical units, such as foot-pounds. Included here are formulæ giving work done by steam, and velocity of steam, from values in "Steam Tables."

TABLE 2

CORRECTION FACTOR FOR ELEVATION

The correction factor given in the table is:

$$-0.00009406\ H_f/980.665 \text{ or}$$
$$-0.0000000959 16\ H_f$$

To correct for elevation we multiply the measurement of a force on a weight scales by the correction factor given, and add it to the reading. (Subtract numerical value of negative correction.)

H Elevation in Feet	[illegible]	Factor
0		0
2000		−0.000192
4000	Helena, Mont.	−0.000384
6000	Colorado Springs, Colo.	−0.000575
8000		−0.000767
10000		−0.000959
12000	Douglas, Mont.	−0.001151
14000	Pikes Peak, Mt. Whitney	−0.001343

[illegible]

Gravity in Formulæ with Forces Due to Earth's Attraction

In cases where g occurs in connection with falling bodies at a particular place, the local g or value at that place must, of course, be used.

Such cases are the direct formulæ for falling bodies at a particular place,

$$s = \tfrac{1}{2} gt^2, \; v = gt, \; v = \sqrt{2\,gs}$$

There must also be included formulæ such as that for the velocity of water due to a head H

$$V = \sqrt{2\,g\,H}$$

Of course, velocity due to pressure p measured in standard pounds per square inch would use the standard g_o. We have, therefore,

$$V = \sqrt{2\,g_o p \,/\, D}$$

where D is density in lbs. cu. ft.

Definition of Horse Power

The horse power was defined by Watt as being 550 foot-pounds per second without consciousness of the distinction between standard and local foot-pounds. To obtain the exactness which is our present object, there must be an additional specification. An exact definition has been adopted by the Bureau of Standards* which has been in some use for many years. This makes the horse power equal to 746 watts. A watt is 10^7 times the work of an erg per second. An erg is a dyne acting through a cm. (0.3937 inches). A dyne is a force which gives a gram an acceleration of a centimeter per second per second.

A standard foot-pound per second is the work done per second by a force of a standard pound acting through a foot. A standard pound is a force which gives a pound (453.59 grams) an acceleration of 980.665 cm. per second per second. Hence there are

$$\frac{746 \times 10^7 \times 0.3937}{980.665 \times 453.59 \times 12} = 550.22$$

standard foot-pounds per second in a horse power. The Bulletin referred to shows that this gives 550 London foot-pounds where Watt made his original definition.

Appendix—Summary of Methods of Computing g

In Coast and Geodetic Survey Publications No. 10 and No. 40 already cited, the computations are made as follows:

* Bulletin 34, Relation of Horse Power to Kilowatt, E. V. Huntington, Bu. Soc. for Pro. Eng. Ed., vol. 5, 1915, page 20.

In all cases the correction for elevation is $-0.0003086\,H$ where H is elevation in meters. Beginning on page 30 of No. 10 are tables from which the rational corrections are made. On page 10 of Publication No. 40 are some corrections in addition to these tables. Beginning on page 20 of No. 40 are the complete corrections for topography and compensation based on a "depth of compensation" of 113.7 kilometers for 219 stations in the United States and other stations elsewhere. The values given are corrections to the fourth decimal place. These corrections are to be made to values given by Helmert's formula of 1901 which is 978.030 $(1+0.005302\,sin^2\,\phi-0.000007\,sin^2\,2\,\phi)$. Beginning on page 50 of No. 40 are the theoretical values per the above formula, the corrections for elevation, corrections for topography and compensation, and observed values of gravity, with the differences, which give the anomalies based on Helmert's 1901 formula.

In order to lessen these anomalies, the following 1912 formula is next used.

$$g_c = 978.038\,(1+0.005302\,sin^2\,\phi \\ -0.000007\,sin^2\,2\,\phi)$$

The theoretical values of gravity are then 0.008 greater than in the table on page 50 and the anomalies 0.008 less. These are called the 1912 anomalies and are listed on page 59. A map, Fig. 11, gives them graphically.

A third method of computation uses the following 1916 formula, 978.040 $(1+0.005302\,sin^2\,\phi-0.000007\,sin^2\,2\,\phi)$. This gives theoretical value of gravity 0.010 greater than computed by the first formula in table on page 50. The corrections for topography and compensation for a "depth of compensation" of 56.9 kilometers are listed on page 100. 0.001 is added to the first term of the 1912 gravity formula on account of the change in the depth of compensation. The formulæ for theoretical gravity at sea level are almost identical for the two depths of compensation, 113.7 and 56.9 kilometers, but the anomalies are different in many cases due to the change in the effect of the isostatic compensation with the depth. The resulting anomalies called the 1916 anomalies are listed on page 103 and page 63 of No. 40, and a map, Fig. 12, is given. The values given in all cases are called the intensity of gravity in "dynes." This is numerically equal to the "falling acceleration," in centimeters per second per second. It is the resultant of the centrifugal

TABLE 3

SAMPLE COMPUTATIONS OF ACCURATE TOTAL CORRECTION FACTOR

We multiply the measurement of a force on a weight scales by the total correction given and add it to the reading (or subtract for a negative correction). For instance, if we had a Prony brake reading of 100 lbs. at Lynn, the correction would be 100× −0.000259, and the corrected force would be 100−0.0259, or 99.9741 lbs.

The Lynn correction is, of course, negligible for engineering work, and even for most physical work. The Deming correction is appreciable for refined physical work, being 16/100 of 1 per cent.

Place	Lynn	Schenectady	Deming
State	Mass.	N. Y.	New Mex.
Latitude, ϕ	42° 28′	42° 45′	32° 20′
Elevation in feet, H_f	20	235	4320
Correction for latitude, Table 1	−0.000283	−0.000257	−0.001175
Correction for elevation, Table 2	−0.000002	−0.000022	−0.000415
Anomaly/1000000, Fig. 1	+0.000026	+0.000040	+0.000011
Total correction factor	−0.000259	−0.000239	−0.001579

TABLE 4

TOTAL GRAVITY CORRECTION FACTOR TO 1/100 OF 1 PER CENT

This is amply accurate for most physical work and more than accurate enough for engineering work. The values are obtained by combining and abridging Tables 1 and 2. The table gives the total correction for latitude and elevation. There is no correction for anomaly for this degree of accuracy. We multiply the measurement of a force on a weight scales by the correction in the body of the table and add it to the reading.

H_f Elevation in Feet / N. Lat. ϕ Degrees	0	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
25	−0.0017	−0.0019	−0.0019	−0.0020	−0.0021	−0.0022	−0.0023	−0.0024	−0.0025	−0.0026	−0.0027
26	−0.0017	−0.0018	−0.0019	−0.0020	−0.0021	−0.0022	−0.0023	−0.0024	−0.0025	−0.0025	−0.0026
27	−0.0016	−0.0017	−0.0018	−0.0019	−0.0020	−0.0021	−0.0022	−0.0023	−0.0024	−0.0025	−0.0026
28	−0.0015	−0.0016	−0.0017	−0.0018	−0.0019	−0.0020	−0.0021	−0.0022	−0.0023	−0.0024	−0.0025
29	−0.0015	−0.0016	−0.0016	−0.0017	−0.0018	−0.0019	−0.0020	−0.0021	−0.0022	−0.0023	−0.0024
30	−0.0014	−0.0015	−0.0016	−0.0017	−0.0018	−0.0019	−0.0020	−0.0020	−0.0021	−0.0022	−0.0023
31	−0.0013	−0.0014	−0.0015	−0.0016	−0.0017	−0.0018	−0.0019	−0.0020	−0.0021	−0.0022	−0.0023
32	−0.0012	−0.0013	−0.0014	−0.0015	−0.0016	−0.0017	−0.0018	−0.0019	−0.0020	−0.0021	−0.0022
33	−0.0011	−0.0012	−0.0013	−0.0014	−0.0015	−0.0016	−0.0017	−0.0018	−0.0019	−0.0020	−0.0021
34	−0.0010	−0.0011	−0.0012	−0.0013	−0.0014	−0.0015	−0.0016	−0.0017	−0.0018	−0.0019	−0.0020
35	−0.0010	−0.0011	−0.0011	−0.0012	−0.0013	−0.0014	−0.0015	−0.0016	−0.0017	−0.0018	−0.0019
36	−0.0009	−0.0010	−0.0011	−0.0012	−0.0013	−0.0014	−0.0015	−0.0015	−0.0016	−0.0017	−0.0018
37	−0.0008	−0.0009	−0.0010	−0.0011	−0.0012	−0.0013	−0.0014	−0.0015	−0.0016	−0.0016	−0.0017
38	−0.0007	−0.0008	−0.0009	−0.0010	−0.0011	−0.0012	−0.0013	−0.0014	−0.0015	−0.0016	−0.0017
39	−0.0006	−0.0007	−0.0008	−0.0009	−0.0010	−0.0011	−0.0012	−0.0013	−0.0014	−0.0015	−0.0016
40	−0.0005	−0.0006	−0.0007	−0.0008	−0.0009	−0.0010	−0.0011	−0.0012	−0.0013	−0.0014	−0.0015
41	−0.0004	−0.0005	−0.0006	−0.0007	−0.0008	−0.0009	−0.0010	−0.0011	−0.0012	−0.0013	−0.0014
42	−0.0003	−0.0004	−0.0005	−0.0006	−0.0007	−0.0008	−0.0009	−0.0010	−0.0011	−0.0012	−0.0013
43	−0.0002	−0.0003	−0.0004	−0.0005	−0.0006	−0.0007	−0.0008	−0.0009	−0.0010	−0.0011	−0.0012
44	−0.0001	−0.0002	−0.0003	−0.0004	−0.0005	−0.0006	−0.0007	−0.0008	−0.0009	−0.0010	−0.0011
45	−0.0001	−0.0002	−0.0002	−0.0003	−0.0004	−0.0005	−0.0006	−0.0007	−0.0008	−0.0009	−0.0010
46	0.0000	−0.0001	−0.0002	−0.0003	−0.0003	−0.0004	−0.0005	−0.0006	−0.0007	−0.0008	−0.0009
47	+0.0001	0.0000	−0.0001	−0.0002	−0.0003	−0.0004	−0.0005	−0.0005	−0.0006	−0.0007	−0.0008
48	+0.0002	+0.0001	0.0000	−0.0001	−0.0002	−0.0003	−0.0004	−0.0004	−0.0005	−0.0006	−0.0007
49	+0.0003	+0.0002	+0.0001	0.0000	−0.0001	−0.0002	−0.0003	−0.0004	−0.0005	−0.0005	−0.0006
50	+0.0004	+0.0003	+0.0002	+0.0001	0.0000	−0.0001	−0.0002	−0.0003	−0.0004	−0.0005	−0.0006

TABLE 5

SAMPLE COMPUTATIONS OF TOTAL CORRECTION FACTOR TO 1/100 OF 1 PER CENT FROM TABLE 4

Place	Lynn	Schenectady	Deming
Latitude, ϕ	42° 28′	42° 45′	32° 20′
Elevation, feet, H_f	20	235	4320
Total correction factor from Table 4	−0.0003	−0.0003	−0.0016

force and the attraction of the earth. Table 6 gives samples of the various numbers involved. The anomalies in each case are of course such as will make the final value by each method exactly equal to the observed value. In addition to the methods in Table 6, there are given values not here included using the "Bouguer" correction for elevation, as well as using the rational method with "depths of compensation" and corresponding standard formulæ, which give smaller average anomalies.

TABLE 6

THEORETICAL COMPUTATIONS OF *g* FROM PUB. 40, PAGE 49, ETC.

Station	Albany, N. Y.	Boston, Mass.	Cambridge, Mass.
Station number	123	29	30
Latitude	42° 39.1′	42° 21.6′	42° 22.8′
Elevation, meters	61	22	14
Theo. *g* (per Helmert 1901, page 49, or Table 1 herewith)	980.404	980.377	980.379
Elevation correction ($-0.0003086\ H$, page 49, or Table 2 herewith)	−0.019	−0.007	−0.004
Corr. for topg. and comp. (113.7 km.), page 50	−0.006	+0.013	+0.010
Anomaly for 1901 formula, page 50	−0.035	+0.013	+0.013
Final *g* by 1901 method	980.344	980.396	980.398
Theo. *g* per 1912 formula (add 0.008)	980.412	980.385	980.387
Elevation correction as above	−0.019	−0.007	−0.004
1912 corr. for topg. and comp. as above	−0.006	+0.013	+0.010
Anomaly for 1912 formula, page 59	−0.043	+0.005	+0.005
Final *g* by 1912 method	980.344	980.396	980.398
Theo. *g* per 1916 formula (add 0.010)	980.414	980.387	980.389
Elevation correction as above	−0.019	−0.007	−0.004
1916 corr. for topg. and comp. (60 km.), page 100	−0.010	+0.008	+0.004
Anomaly for 1916 formula, page 103	−0.041	+0.008	+0.009
Final *g* by 1916 method	980.344	980.396	980.398
Theo. *g* (per Helmert 1901 formula, page 49, or Table 1 herewith)	980.404	980.377	980.379
Elevation correction ($-0.0003086\ H$, page 49, or Table 2 herewith)	−0.019	−0.007	−0.004
Free air anomaly by page 59 or map, Fig. 1, herewith	−0.041	+0.026	+0.023
Final *g* by free air method used in this article	980.344	980.396	980.398

Fundamentals of Illumination Design

Part I. FUNDAMENTAL CONCEPTS

By Ward Harrison *
Illuminating Engineer, National Lamp Works of G. E. Co.

The science of illumination has been wonderfully furthered by electrical engineers during the past decade, and is now established on a firm foundation. Illuminating engineers have convincingly demonstrated the great advantages that result from correctly designed lighting installations; and where relatively a few years ago little consideration was given to the elimination of glare, suitable intensities and color value, and proper diffusion, all of these factors are now studied with the greatest care. Today the question of illumination in any large undertaking is almost the first consideration. In this series of articles the author has outlined the principles that enter into illumination design, and the subject matter has been divided under four headings, viz., Fundamental Concepts, Illumination Design, Reflectors and Enclosing Glassware, and Illustrative Problems of Lighting, each of which will be published as a separate chapter.—Editor.

A mastery of the principles of illumination can be gained only by studying the subject from the ground up. In this, as in other scientific subjects, it is necessary at the outset for us to familiarize ourselves with the various terms used in the art, especially those terms which designate units of measurement, for these terms constitute the foundation work upon which the final structure is to be built. Basic definitions have a very academic and sometimes a very technical sound, although the units themselves, once their definitions have been assimilated and not merely learned by rote, are comparatively simple. The definitions which appear from time to time in this paper need not, therefore, be committed to memory, but should be thoroughly digested so that the reader will grasp the distinction between the different units, and obtain a working knowledge of what each stands for and the quantity it represents. In illumination it is of more practical value to have a conception of the quantity of light represented by one lumen — to know that, for example, 75 of these units represent the quantity of light given off by a 10-watt lamp—than it is to be able to tell precisely what a lumen is. If the unit of length which we call a mile were arbitrarily made shorter, the distance between New York and Chicago would still be the same, or if the day were divided into ten equal parts instead of 24 hours, the planets would not change their speed of travel or rate of rotation. Obviously, it is of advantage to standardize certain units so that relations of magnitude can be expressed and understood with precision, although the value we arbitrarily assign as a standard is of little importance except from this standpoint.

UNITS OF MEASUREMENT

The Candle

A generation or two ago when new light sources began to supersede the candle, it was most natural that the illuminating power of these new sources should be expressed in terms of the candle familiar to all. It is probable that the very first comparisons of two light sources were made by setting up the two lamps in the line of vision and gauging them by means of the eye, the most natural direction in which to look at the sources being the horizontal. A glance at Fig. 1 shows that the eye (an extremely fallible instrument of light measurement at its best) is capable of measuring only a very slender cone of light at one time; in fact, if the eye is an appreciable distance from the source, the cone *RST* becomes virtually a single line. While there are an infinite number of directions from which the eye might look at the source, the light-giving power in a horizontal direction was made the basis of comparisons, and the strength of the light in this direction from a candle made according to certain definite specifica-

Fig. 1. Only a Slender Cone of Light Reaches the Eye

*The author is indebted to Evan J. Edwards and R. W. Shenton of the National Lamp Works for their co-operation in the preparation of this series of articles.

tions, was arbitrarily chosen as the unit of intensity and called a *candle*. The newer illuminants appearing on the scene were rated according to their strength in this same direction and were stated to give so many candles, so that when we say a lamp gives

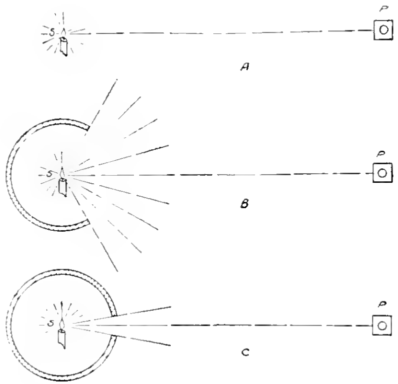


Fig. 2. The Candle-power in the Direction of the Photometer is Not Changed by Partially Surrounding the Light Source With a Non-Reflecting Surface

10 candles, we really mean that its intensity or strength in a horizontal direction is equal to that of a group of ten standard candles. This rating of a lamp is made by means of an instrument known as a photometer, a description of which will be given later. One essential point to remember in this connection is that the candle-power of a lamp represents the intensity in one direction only. In practice it has been customary for years to rotate the lamp about a vertical axis while the candle-power was being determined and the result was known as the mean or average horizontal candle-power, but even this determination gives an average value of the intensity in the horizontal direction only. It should be stated, however, that in comparing lamps on the basis of their horizontal candle-power, the light in directions other than the horizontal was not really ignored, for it was taken into consideration that most sources of light then in use gave off their light in about the same proportions in the different directions and that for this reason the candle-power in a single direction furnished a criterion sufficiently accurate for the needs of the time.

To carry our conception of candle-power a little further, let us assume the conditions existing in Fig. 2. In Case A we have on the left a standard candle and on the right a photometer pointed toward the candle. From what has already been stated, it is obvious that when the photometer is balanced it will indicate an intensity of one candle. In Case B we have surrounded the same candle with a sphere having a moderately large opening. The inside of the sphere, we will say, has been painted a dead black so that none of the rays striking it are reflected but are absorbed and cease to be light—in other words, are thrown away as far as our experiment is concerned. In this case the photometer will still indicate an intensity of one candle in spite of the fact that a great deal of light has been thrown away. In Case C, we have used a sphere with a much smaller opening and are therefore wasting still more of the light, but even in this case our photometer will indicate an intensity of one candle. In fact, our reading will be one candle regardless of the size of the opening, that is, regardless of the quantity of light we allow to be emitted, provided the direct rays from the candle to the photometer are not obstructed. The proverbial candle hidden under a bushel will still give an intensity of one candle if there is a small hole in the bushel for a beam to escape, although as far as its illuminating value is concerned, it is still "hidden under a bushel." This leads us to the important conclusion that the candle-power of a source gives no indication of the total quantity of light emitted by that source. Candle-power, we may say, is analogous to a measurement of the depth of a pool of water at a certain point on its surface—a measurement which is useful for certain purposes but in itself gives no indication of the quantity of water in the pool.

The first fundamental concept we have to deal with in illumination, then, is candle-power, which is the measure of strength of a source to produce illumination in a given direction, and the power in a horizontal direction of a candle made according to certain specifications and burning under certain conditions has been arbitrarily chosen as the unit for measuring this strength.

Closely related to candle-power is *mean spherical candle-power* The mean spherical candle-power of a lamp is simply the average of all the candle-powers in all directions about that lamp. A source giving one candle in every direction would have a mean spherical candle-power of 1, or if a source gave off various candle-powers in different directions but if the average of all these candle-powers were 1, this source would have a mean spherical candle-power of 1. We must remember, however, that the infinite number of directions in which a source ordinarily emits light do not all lie in the same plane, but extend into space on all sides about the source, like the pricks of a chestnut burr.

The Lumen

We have seen from Fig. 2 that candle-power alone gives no indication of quantity* of light. It is necessary, therefore, for us to develop a unit whereby we can measure the quantity of total flux of light emitted by a source. For this purpose let us assume a source giving one candle in every direction, and that this source is placed at the center of a sphere painted black on the inside and having a radius of, say, 1 foot, as shown in A, Fig. 3. *OR* represents an opening in the sphere through which some of the light may escape. The quantity of light allowed to escape may be varied by varying the size of the opening, with the candle-power of the source and the radius of the sphere remaining fixed; if we decide on some definite size of opening at *OR* we shall have a definite quantity of light which we can use as our unit for measuring quantity. The simplest area or unit to assume for *OR* is 1 square foot and if we make this opening of an area of 1 square foot, the amount of light that escapes is considered to be the unit of quantity, and is called a *lumen*.† Thus we have established a permanent unit for the measurement of quantity of light; the mathematical relations used to fix it serve only the same purpose as two scratches on a platinum iridium bar in the International Bureau of Weights and Measures, the distance between which at a definite temperature is called a meter.

If the area of *OR* is made $\frac{1}{4}$ square foot, the light escaping will amount to $\frac{1}{4}$ lumen; if the area of *OR* is doubled, the light escaping will be 2 lumens. On the other hand, if we have a uniform source of 2 candles instead of 1, 2 lumens will be emitted through an opening of 1 square foot in this particular sphere. We know by arithmetic that the total surface of the sphere having a radius of 1 foot is 12.57 square feet.‡ In other words, removing the sphere entirely, we would have the equivalent of 12.57 openings the size of *OR*; that is, if the candle gives 1 candle in every direction, with the sphere removed it would give 12.57 lumens. This means that if we know the mean spherical candle-power of a lamp, by multiplying this value by 12.57 we obtain the number of lumens emitted by that lamp. A value of $12\frac{1}{2}$ is sufficiently accurate for most practical purposes and is somewhat more convenient for calculation inasmuch as it is necessary only to divide the mean spherical candle-power by 8, with proper regard to the decimal point, to arrive at the lumen rating. A lumen may also be defined as being equivalent to the quantity of light intercepted by a surface of 1 square foot every point of which is at a distance of 1 foot from a source of 1 candle. (Fig. 3, Sketch B.)

While the foregoing definitions establish definitely the quantity of light that we use as our basic unit, it must be remembered

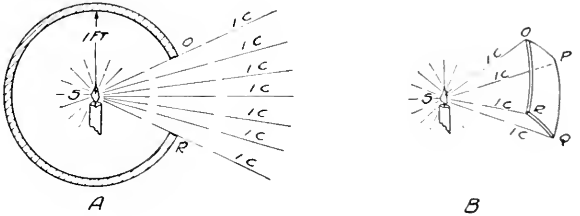


Fig. 3. A—Opening *OR* has Area of One Square Foot and Emits One Lumen
B—One Lumen Falls on Surface *OPQR*

*Quantity is here used in the sense that it indicates only a summation of flux as throughout a given solid angle about the source, and over a given area illuminated to some average value. Quantity in a more precise sense is a summation over a period of time and is measured in lumen-hours.

†We could choose a sphere of any radius we cared to, as long as we kept the proportion the same by making the size of the opening such that its area would be equal to the square of the radius. The quantity would still be one lumen.

‡The surface of a sphere is equal to the radius squared multiplied by 4 by 3.1416.

that a lumen, in order to be a lumen, need not necessarily conform with these specifications if the quantity of light represented is equivalent to that prescribed by the definition. A bushel might be defined as the quantity of any commodity contained in a cylindrical measure having a diameter of $18\frac{1}{2}$ inches and a height of 8 inches; however, a bushel of potatoes spread out in the field is just as much a bushel as though the shape of the pile conformed in every respect to the dimensions just mentioned.

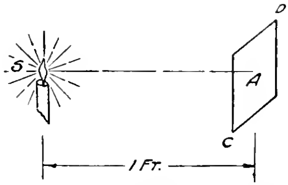


Fig. 4. The Illumination at A is One Foot-candle

The Foot-candle

Light is a cause and illumination the effect or result. Both the lumen and the candle are used to measure the cause, these units applying to the light source itself and not to the point where the light is utilized. To measure the illumination on a newspaper, desk, or other working plane, we employ a unit called the *foot-candle*. A foot-candle represents an intensity of illumination equal to that produced at a point on a plane which is 1 foot distant from a source of 1 candle and which is perpendicular to the light rays at that point. In Fig. 4, if the source S gives an intensity of 1 candle along the line SA and if A is 1 foot distant from the source, the intensity of illumination on the plane CD at the point A is 1 foot-candle.* The intensity of illumination, measured in foot-candles, is the unit of measurement most intimately associated with our everyday use of light, and a measurement which the eye either consciously or unconsciously is making whenever the faculty of vision is being employed, for the number of foot-candles we have on the working plane, other things being equal, determines directly whether or not there is sufficient light. A working idea of a foot-candle of illumination can be obtained by considering the intensity on a newspaper being read by the light of a candle, the paper being held approximately one foot away from the candle. The foot-candle is a unit applying to a point on a surface; by averaging the foot-candles at a number of points on a plane, we get the average intensity of illumination on that plane.

Care should be taken to avoid confusing the intensity of illumination on a surface as indicated by the foot-candles with the appearance as regards brightness of the surface. A grey surface lighted to an intensity of one foot-candle will not appear so bright as a white one, for a greater proportion of the light falling upon the plane is absorbed and lost. The brightness of an object depends upon both the intensity of illumination on it and the percentage of light that it reflects.

Having defined the foot-candle as a unit of intensity of illumination, we are naturally interested in seeing how the intensity of illumination varies as the candle-power of the source varies, and also as the distance of the plane from the source varies. It is obvious that if in Fig. 4 instead of an intensity of 1 candle along the line SA we have an intensity of 2 candles, the illumination at A would be twice as great, and that if we have an intensity of 5 candles the illumination at A will be five times as great. Now, if we consider a source of 1 candle as shown in Fig. 6, we know that the intensity of illumination on A which is 1 foot distant is 1 foot-candle. If, however, we remove the plane A and allow the same beam of light that formerly was intercepted by A to pass on to the plane B, 2 feet away, we find as shown in the

Fig. 5. The Illumination is Less on $A'B'$ than on AB (See Footnote)

*If, instead of being perpendicular to the beam, the plane AB is tilted at an angle, as shown in Fig. 5, it will be seen that the light of this beam is spread over a greater area than if the plane is perpendicular, so that the intensity of illumination on the plane is less in proportion to the ratio of the length of AB to the length of $A'B'$ or to the cosine of the angle between a perpendicular to $A'B'$ and the axis of the beam, which is the angle X. If with the plane in the position AB the illumination is 1 foot-candle and the cosine of the angle X is 0.7, the average illumination on the plane in position $A'B'$ will be only 0.7 of a foot-candle.

diagram that this same beam of light would have to cover four times the area of A; and, inasmuch as we cannot get something for nothing, we would find that the average intensity on B, 2 feet away, would be ¼ as high as that on A, 1 foot away, or ¼ of a foot-candle. In the same way, if B also is removed and the same beam allowed to fall upon plane C, 3 feet away from the source, it will be spread over an area nine times as great as A, and so on; at a distance of 5 feet we would have only $^1/_{25}$ of a foot-candle. From this we deduce that the intensity of illumination falls off not in proportion to the distance, but in proportion to the square of the distance. This relation is commonly known as the inverse square law.

Important Relation Between Foot-candle and Lumen

If we refer back to Fig. 3B we see that the surface *OPQR* is illuminated at every point to an intensity of 1 foot-candle. We also know by definition that the quantity of light falling on the plane *OPQR* is 1 lumen. This gives us the important law that if 1 lumen is so utilized that all of the light is spread over a surface of 1 square foot, that surface will be lighted to an average intensity of 1 foot-candle. This relation greatly simplifies the designing of a lighting installation, for once the number of square feet to be lighted and the intensity of illumination which it is desired to provide are known, it is a simple matter to find how many lumens must fall on the working plane. If, for example, it is desired to illuminate a surface of 100 square feet to an average intensity of 5 foot-candles, 500 lumens must be utilized The designing of a lighting installation is taken up more in detail in a succeeding issue.

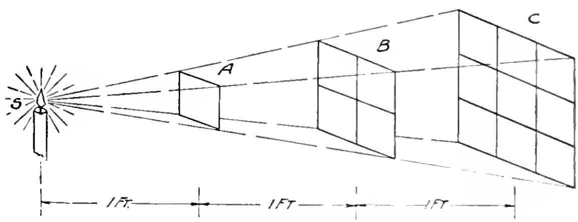


Fig. 6. The Illumination on a Surface Varies Inversely as the Square of the Distance from the Source to the Surface

PHOTOMETRY

Candle-power and Light-output Measurements

Photometry is a specialized branch of the science of illumination which in itself may be made the subject of an extended study. The man doing field work in illumination has no need for an intimate knowledge of all the details that enter into this branch of the art. In the following discussion, photometers are treated in a broad, general way, and for more detailed description of these instruments the reader is referred to standard works on the subject of illumination and photometry.

A sketch of the simplest type of photometer is given in Fig. 7. The essential part of this photometer is a vertical paper screen between the lamps to be compared, at the center of which is a grease spot. When the illumination on one side of the screen is greater than that on the other, the spot on this side will appear darker and on the other side lighter than the surrounding paper. By sliding the screen back and forth on the bar, a position can be found where the outlines of the spot will vanish and the spot itself will disappear. When this condition obtains, the illumination on both sides of the screen is the same.

In order that both sides of the screen may be seen simultaneously, mirrors are mounted obliquely behind the screen. In Fig. 8, Case A, it will be noted that the spot as viewed in the left-hand mirror is darker than its surroundings and as viewed in the right-hand mirror is lighter than its surroundings, which indicates that the left-hand side of the screen is illuminated to a higher intensity than the right. In Case B of the same figure, it will be noted that the conditions are reversed; therefore, in this case the illumination on the right side of the screen is greater than that on the left. Somewhere between these two positions is a position at which the spot will cease to be visible, as shown in Case C of Fig. 8.

From what has been said above, the intensities of illumination on both sides of the screen in Case C are equal. Now, since we have a relation between the intensities of illumination that the two lamps being compared produce, we can reason back as to the relation between the candle-powers given, respectively, by lamps A and B (see Fig. 8). The scale of the photometer shows us that at a distance of 60 inches the lamp A produces an illumination equal to that which the lamp B can produce at a distance of 40 inches. At first thought we might say that A must give 3/2 as great a candle-power as B, but recalling the inverse square law referred to on page 357, which states that the intensity of illumination varies inversely as the square of the distance, or, what is the same thing, that the candle-power necessary to produce a given illumination varies as the square of the distance from the source to the plane, we see that the ratio of the candle-power of A to that of B instead of being 3 to 2 is 3^2 to 2^2 or 9 to 4. The horizontal candle-power of A, therefore, is $2\frac{1}{4}$ times that of B. If B is a lamp of some known candle-power, the candle-power of A is determined by multiplying the candle-power of B by $2\frac{1}{4}$. The general rule, then, is that the candle-powers of two lamps on a photometer are to each other as the squares of the distances from each to the screen are to each other. For accurate photometry, the grease spot screen is no longer in use, but the newer and more accurate photometers are the same in principle.

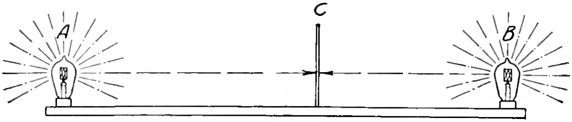


Fig. 7. Essential Parts of Horizontal Photometer

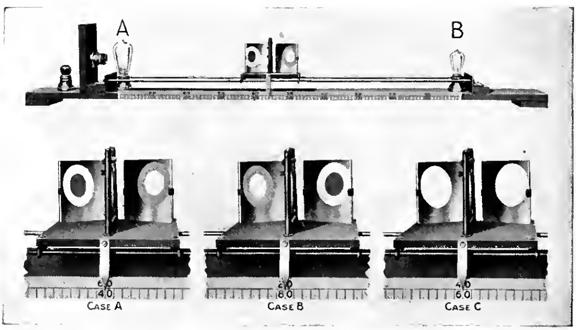


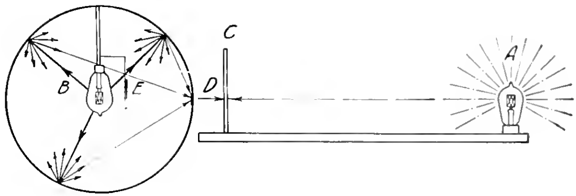
Fig. 8. Photometer and Screens
Case A—Screen at Left of Balance Point
Case B—Screen at Right of Balance Point
Case C—Screen at Balance Point

The simple bar photometer measures candle-power in one direction only. If the lamp being measured is rotated about its vertical axis, its mean horizontal candle-power is obtained. In like manner, if the vertical axis of the lamp being measured is tipped and the lamp rotated on this axis, the average candle-power at any angle can be determined.

Another form of photometer known as the sphere photometer, or Ulbricht sphere, is shown in Fig. 9. In this photometer the lamp to be measured is placed at the center of a large sphere the inside of which is painted flat white. In this sphere is a small window of milk glass. The candle-power emitted by this window is compared with the candle-power of a standard lamp. The candle-power of the window computed as above is directly proportional to the mean

Foot-candle Measurements

It will be noted that in measuring the *candle-power* of light sources as discussed above, we balance the *illumination* on opposite sides of a screen. Often, however, we are interested in the illumination itself, that is, the foot-candle intensity which is being supplied any given area, and care very little about the candle-power of the sources which



Diagrammatic Sketch of Photometer

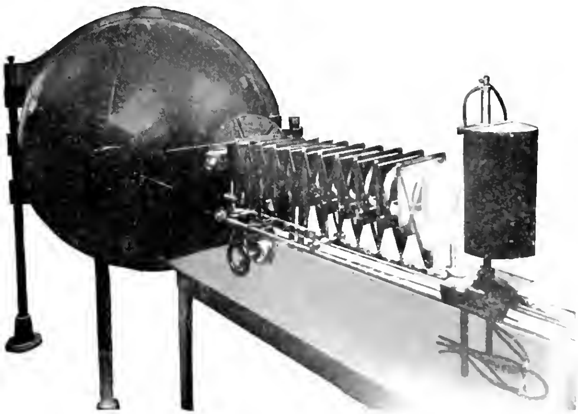


Fig. 9. Sphere Photometer

spherical candle-power or the total lumen output of the lamp in the sphere,* so that multiplying this candle-power by a constant factor which has been determined for this particular sphere gives the total lumen output direct. Thus at one reading the mean spherical candle-power or the total lumen output of a lamp can be determined.

*That the above condition is true can be proved mathematically, but it is believed that a discussion of this proof, important as it is in simplifying the operation of determining total light output, would be beyond the scope of this publication.

supply the illumination. If we calculate the different foot-candle intensities to which one side of the screen of a photometer is illuminated when the distance between the screen and the standard lamp is varied, and then place the screen so that the illumination we wish to measure falls upon the opposite side of the screen, the balance of the photometer will give us a measurement of the foot-candle intensity. The differences between photometers used for measuring candle-power and those used for measuring foot-candles are chiefly ones of form and calibration.

An instrument called the foot-candle meter has recently been designed to measure foot-candle intensities quickly and with a fair degree of accuracy. It is very simple in operation, so light that it can be easily carried about, and so small that readings can be taken in very restricted spaces. The instrument is shown in Fig. 10. In operation, it is placed upon or adjacent to the surface on which a measurement of the foot-candle intensity is desired. A lamp within the box illuminates the under side of the screen to a much higher intensity at one end than at the other. The illumination which it is desired to measure is, of course, practically uniform over the entire scale. Closely spaced translucent dots, which serve the same purpose as the grease spot in the simple bar photometer, line the scale from end to end. If the illumination on the scale from the outside falls within the measuring limits of the meter (0.5—25 foot-candles) the spots will appear brighter at one end of the scale than at the other, and at the point where the spots are neither brighter nor darker than the white paper scale the illuminations from within and from without are equal. The scale is accurately calibrated with the lamp within the box burning at a certain definite voltage. A voltmeter and rheostat permits the operator to adjust the lamp voltage to that at which the instrument was originally calibrated. The energy is supplied from small dry cells.

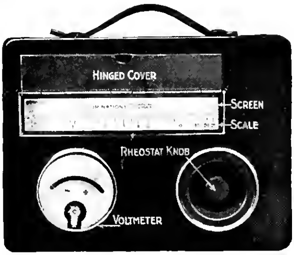


Fig. 10. Foot-candle Meter

This instrument is proving very serviceable for "checking up" installations to insure, for example, that the illumination is ample when the lighting equipment is in first-class shape and to see that it is not allowed to fall below a desirable value due to improper care and attention being given to the lighting system. Those who by reason of their experience are enabled to plan an illumination layout without direct reference to spacing tables, formulas, etc., should find this instrument of special value in securing data which can be applied in the designing of future installations.

THE CANDLE-POWER DISTRIBUTION CURVE

The candle-power distribution curve of a lamp or unit was at one time widely used in calculating illumination intensities, but the greater simplicity and accuracy of the lumen method of computing illumination has resulted in the former method falling into disuse. Distribution curves are now used principally for comparing the suitability of reflectors for use in a given location from the standpoints, particularly, of light distribution and light absorption.

ANGLE	CANDLE-POWER	ZONE	LUMENS
0	142.0		
5	148.0	0-10	14
15	161.0	0-20	60
25	178.0	0-30	142
35	193.0	0-40	257
45	181.0	0-50	397
55	165.0	0-60	545
65	108.0	0-70	652
75	44.1	0-80	699
85	5.1	0-90	704
90			

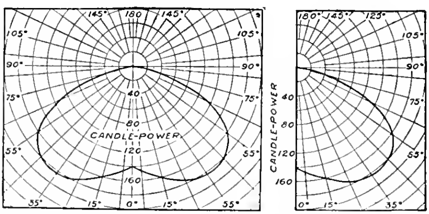


Fig. 11. Three Methods of Recording Candle-power Distribution Data

Figure 11 presents three methods of showing the manner in which the candle-power of a unit measured at different angles can be recorded. The value at any angle represents the average candle-power of the source at that angle as the source rotates about its vertical axis. At the left of the figure the data are given in tabular form; at the center and the right they are plotted to polar co-ordinates. Distribution curves are used simply as a graphical method for presenting the data given in the table on the left. All have exactly the same meaning. A distribution curve is a graphical—not a pictorial—representation of the light distribution from a source, although its general shape might convey the wrong impression. It is simply a convenient engineering method of presenting tabulated data graphically.

The area of a distribution curve is not a criterion of the total amount of light emitted by a source. In Fig. 12, both curves shown are taken from units giving exactly the same total lumens with different distributions of candle-power; although Curve B appears from the distribution curve to represent much more light than A, the amount of light given off is the same in each case.

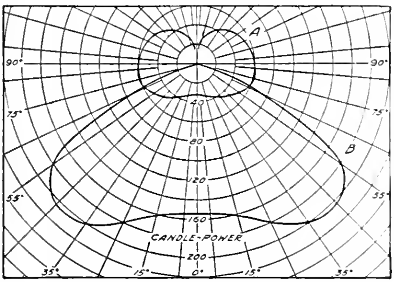


Fig. 12. The Area of a Distribution Curve is not a Criterion for Judging Light Output. These Two Curves Represent Equal Light Outputs

Another common error in regard to distribution curves is to assume that simply taking the arithmetical average of the candle-powers at different angles, as shown on the distribution curve, will give the mean spherical candle-power of the unit represented. To make the true relation clear, let us assume a May Pole set up at the middle of a hemispherical hollow and that one girl carries a streamer making an angle of 45 degrees with the vertical and another carries one making an angle of 15 degrees with the vertical. Due to the contour of the ground about the pole, both ribbons will be of the same length. Now, keeping our candle-power distribution curves in mind, let us assume that the tip of the pole is the light source under consideration and that the length of each streamer represents the candle-power in its particular direction. It is obvious that in order to make one revolution about the pole, the girl holding the 45-degree streamer must travel a much greater distance than the other. In other words, she makes a bigger contribution to the general effect produced by the May Pole. In fact, because of the greater circle she must describe, she has to do 2.7 times as much work as the girl carrying the 15-degree streamer. In the erroneous use of a distribution curve just referred to, only the length of the ribbon is taken into consideration. From our analogy it is apparent that the zone of travel of the ribbon, or the complete zone in which the candle-power at a given angle is effective, must also be taken into account. Just as in our May Pole the girl taking the 45-degree circle does 2.7 times as much work as the girl in the 15-degree circle, so the quantity of light necessary to maintain an intensity of one candle throughout the 45-degree zone contributes 2.7 times as much to the total light output of the lamp as the quantity of light required to maintain one candle throughout the 15-degree zone. In other words, the farther up from the vertical and toward the horizontal the candle-power shown on the distribution curve, the more weight it must be given as regards its contribution to the total quantity of light emitted by the source.

In calculating the flux of light in various zones, we usually find it convenient to calculate for zones of 10 degrees, and it is sufficiently accurate for most purposes to assume that the candle-power value at the center of each 10-degree zone represents the average candle-power of the zone. The following are the factors by which such candle-power values should be multiplied to give the lumens in each 10-degree zone

Zone	Factor to Obtain Lumens from Average C-P.
0°—10°	0.0954
10°—20°	0.283
20°—30°	0.463
30°—40°	0.628
40°—50°	0.774
50°—60°	0.897
60°—70°	0.992
70°—80°	1.058
80°—90°	1.091

Above 90 degrees the factors are the same but in the reverse order.

To use these factors with the curve of any light unit, we take the candle-power at 5 degrees and multiply it by the 0-10 degree factor to obtain lumens in the 0-10 degree zone; we take the candle-power at 15 degrees and multiply it by the 10-20 degree zone factor to obtain the lumens in the 10-20 degree zone, etc. The total lumen for any large zone is the sum of the lumens thus determined in all of the 10-degree sections of the zone.

Another method of determining the flux in any 10-degree zone is as follows: We first measure the horizontal distance between the vertical axis and the point where the candle-power curve crosses the center of the zone under consideration. We then lay off this distance on the candle-power scale to which the curve is plotted. By adding 10 per cent to this figure, we obtain a value which represents the lumens in that zone. Where it is desired to obtain the summation of the lumens in a number of 10-degree zones, for example, from 0 degrees to 60 degrees, it is convenient to mark off these horizontal distances (to the center of each 10-degree zone) successively on the edge of a sheet of paper. The value for the total lumens is then found by simply laying off the total length thus found on the candle-power scale and adding 10 per cent to the result. The results obtained by this method, neglecting possible errors of measurement, are accurate within 0.2 of one per cent.

(To be continued)

The 3000-volt D-C. Gearless Locomotive for the Chicago, Milwaukee and St. Paul Railroad*

By A. H. Armstrong

Chairman of the Electrification Committee

The advantage of the gearless locomotive manifests itself chiefly in passenger service on long stretches of level track or easy grades, where high speeds may be maintained for the greater part of the running time. For the low speeds of heavy freight trains there is little difference in efficiency between geared and gearless construction, the advantage, if any, being in favor of the former. The gearless locomotive described in this article will be employed for passenger service on the Seattle extension of the C., M. & St. P. It will be guaranteed capable of hauling a 12-car train weighing 960 tons up a 2 per cent grade at 25 miles per hour, which is very conservative; actually the locomotives will be capable of hauling 13 or 14 cars with practically no sacrifice in schedule speed. The excellent performance of the gearless locomotives on the New York Central Railroad is responsible for the adoption of this type of locomotive by the C., M. & St. P.—Editor.

The excellent operating results obtained during the past ten years with gearless motor locomotives on the New York Central tracks have attracted increasing attention to this form of construction. The extreme simplicity in design offered by mounting the armature directly upon the driving axle, thus eliminating all gears, quills, jack-shafts, side rods, etc., has resulted in great reliability and low cost of maintenance. It is, therefore, an achievement of much importance to announce the entry of the gearless locomotive in mountain-grade haulage, as it can be reasonably expected that this type of construction holds promise of equally good operation in this heaviest class of railroad service.

The gearless locomotive now under construction for the Chicago, Milwaukee & St. Paul extension to Seattle is equipped with fourteen axles, twelve of which are drivers and two guiding axles. The armature is mounted directly upon the axle and, with the wheels, constitutes the only dead or non-springborne weight of the locomotive. The dead weight is approximately 9500 lb. as compared with 17,000 lb. on the driving axles of the present geared locomotive now in operation on the Chicago, Milwaukee & St. Paul. The two fields are carried upon the truck springs and there is full freedom for vertical play of the armature between them. The construction of the motors throughout is practically identical with that employed upon the New York Central gearless locomotives, but the capacity of the locomotive is much increased and the wheel is arranged somewhat different. Table I gives the general physical characteristics of the locomotives now under construction.

*Abstract of talk before New York Railroad Club, "Electrical [illegible]," March 15, 1918.

TABLE I

DIMENSIONS AND WEIGHTS

C., M. & St. P. 3000-volt, Direct-current, Gearless Locomotive

Length inside knuckles	76 ft. 0 in.
Length over cab	68 ft. 0 in.
Total wheel base	67 ft. 0 in.
Rigid wheel base	13 ft. 11 in.
Diameter driving wheels	44 in.
Diameter guiding wheels	36 in.
Approximate height center of gravity	57 in.
Weight electrical equipment	235,000 lb.
Weight mechanical equipment	295,000 lb.
Weight complete locomotive	530,000 lb.
Weight on drivers	458,000 lb.
Weight on guiding axle	36,000 lb.
Weight on each driving axle	38,166 lb.
Dead or non-springborne weight per axle	9,500 lb.

With twelve motors per locomotive available for different control combinations, there is an unusual opportunity to secure a wide range_of speeds to meet the varying conditions of passenger train operation. Motors are connected three in series or 1000 volts per commutator for full-speed operation, but the control also permits a connection of four, six, or twelve motors in series for fractional-speed operation. Further provisions for variable speed are made by shunting the motor fields in all combinations of motors, but it is probable that the greatest value of field shunt will be obtained with the full-speed connection of three motors in series. Table II illustrates the speed possibilities of this locomotive.

It is especially desirable that a passenger locomotive shall have sufficient weight on the drivers and reserve motor power to haul additional train weight on occasion, and in this respect the gearless locomotive under construction presents some attractive possibilities. The manufacturer's guarantees cover the operation of a twelve-car train weighing 960 tons against an adverse grade of 2 per cent at a speed of 25 miles per hour. Under these conditions there is a demand for 55,200 lb. tractive effort at the rim of the drivers, equivalent to 12 per cent coefficient of adhesion of the weight upon the drivers. There is, therefore, ample margin, both in weight upon drivers and capacity of motors, to haul not only twelve cars but on occasion thirteen or fourteen cars with practically no sacrifice in schedule speed and without overloading the motors or exceeding known and conservative practice as regards loading of driving wheels. For example, the gearless locomotive being built will permit the starting of a twelve-car train on a 2 per cent grade with a coefficient of adhesion of only 20 per cent and the accelerating of the train at 0.3 miles per hour per second. These general statements are itemized in Table II

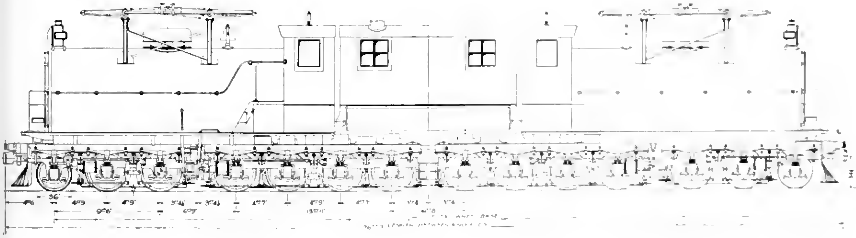


Fig. 1. Outline of Chicago, Milwaukee & St. Paul Gearless Passenger Locomotive

While the manufacturing guarantees are limited to 42,000 lb. tractive effort as a continuous output of this locomotive, preliminary tests upon a sample motor built indicate that

TABLE II

SPEED CHARACTERISTICS

C., M. & St. P. 3000-volt, Direct-current, Gearless Locomotive 960 Tons Trailing Load

	Level	½ Per Cent Grade	1 Per Cent Grade	2 Per Cent Grade
3 motors in series, shunted field	63.0	47.2	38.5	30.5
3 motors in series, full field	49.5	36.0	30.0	25.0
4 motors in series, full field	40.5	27.0	22.0	18.0
6 motors in series, full field	29.0	17.8	14.2	11.0
12 motors in series, full field	15.0	8.0	6.0	4.0

this rating is conservative and that the final tests upon a complete locomotive when finished may show values materially higher than the guarantees made. This fact is of the greatest importance and holds out wide visions of radical changes in the operation of trans-continental trains, both passenger and freight. The total weight upon drivers of 458,000 lb. is practically the same as the

Fig. 3. New York Central Locomotive Showing Method of Removing Wheels and Motor Armature

driver weight of the present freight locomotive now in operation on the Chicago, Milwaukee & St. Paul.

If, therefore, the completed locomotive meets the expectations of the builder, it offers the possibility of using the same locomotive interchangeably for both passenger and freight service. The considerable speed variation permitted with four motor combinations insures a means of operating the locomotive at any speed demanded by the character of service to which it is assigned. Furthermore, when operating a freight train at lower speeds it can reasonably be expected that the tractive effort rating of the locomotive will be increased, due to the lower core loss at the lower armature speeds. While not primarily designed as an interchangeable locomotive, it is quite possible that the flexibility of this new Chicago, Milwaukee & St. Paul gearless locomotive will become increasingly apparent when it is put into operation and its fitness for freight service will be fully recognized. It is needless to forecast the operating benefits that would result from having only one class of locomotive assigned to the road movement of either passenger or freight trains. Just as the Chicago, Milwaukee & St. Paul Railway, the pioneer road in long distance electrification, utilized for the first time 3000-volt direct current, and employed regenerative electric braking

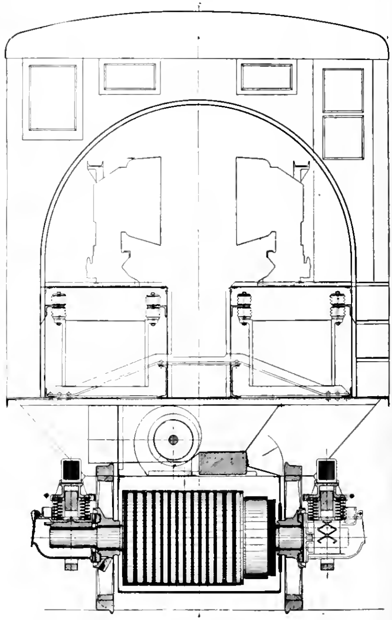


Fig. 2. End Elevation of Chicago, Milwaukee & St. Paul Locomotive Showing Location of Armature and Control Equipment

TABLE III

HAULING CAPACITY

C., M. & St. P. 3000-volt, Direct-current, Gearless Locomotive

Number of motors	12
One hour rating	3240 h.p.
Continuous rating	2760 h.p.
Tractive effort 1 hour rating	46,000 lb.
Tractive effort continuous rating	42,000 lb.
Tractive effort 2 per cent ruling grade with 960-ton train	55,200 lb.
Coefficient of adhesion ruling grade	12 per cent
Starting tractive effort 20 per cent coefficient of adhesion	91,600 lb.
Rate of acceleration starting 2 per cent ruling grade	0.3 m.p.h.p.s.

on down grades, so also this road may introduce radical changes in the road movement of passenger and freight trains by reason of the great flexibility offered in the gearless locomotive which will be put into operation within the year.

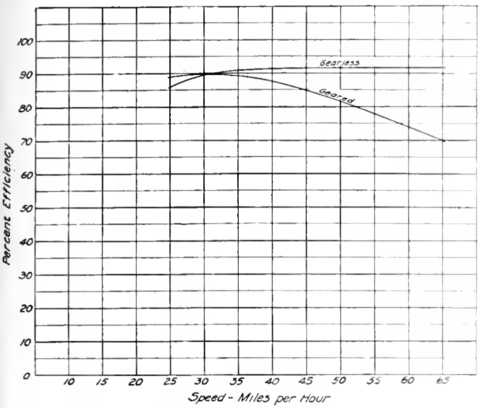


Fig. 4. Efficiency Curves of Present Geared and New Gearless Chicago, Milwaukee & St. Paul Locomotive

The control of the gearless locomotive will in many respects be a duplicate of that now in successful operation on the geared motor locomotive previously installed. Provision will be made for regenerative electric braking on down grades, as the success and operating value of this method of holding trains on down grades has been fully established during the past two years of electrical operation on the Chicago, Milwaukee & St. Paul Railway. The geared locomotives now running utilize a motor-generator set for exciting the motor field while regenerating, and the results with this combination have been excellent. Careful experiments made during the past two years have demonstrated that motor-generator field excitation is not essential and, taking advantage of the advance of the art, the control for the new gearless locomotive will dispense with this feature. This simplification of the control and reduction in weight and cost constitutes a marked improvement. It is estimated that approximately 25 per cent of the 550,000,000 tons of coal mined in the United States during 1917 was consumed under the boilers of steam engines hauling our railway tonnage. One of the greatest arguments for electrification is the saving of fuel effected; and, therefore, it is very essential that the efficiency of electric locomotives be raised as high as possible in order to fulfill one of the claims for their introduction. In this respect the gearless locomotive under construction offers a marked improvement as compared with the geared motor locomotive.

The original installation of the Chicago, Milwaukee & St. Paul was undertaken with a single type of road locomotive for both passenger and freight service, differing only in the ratio of the gearing between the motors and drivers. The locomotives were therefore interchangeable, except as to gears, with consequent

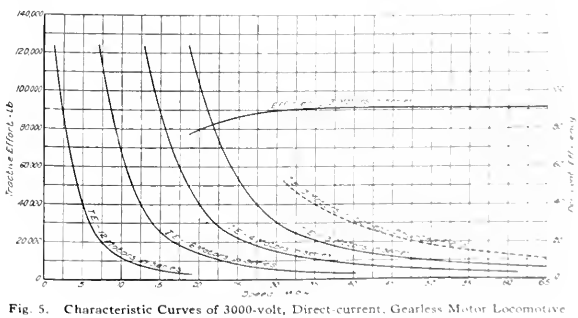


Fig. 5. Characteristic Curves of 3000-volt, Direct-current, Gearless Motor Locomotive for Chicago, Milwaukee & St. Paul Railroad

simplification of shop repair practice. The geared locomotive operates at a high efficiency in heavy freight service where pushers are used on up grades; but accumulative gear losses result in a low all-day efficiency of a geared locomotive in passenger service, when the profile is broken and contains long stretches of practically level track. On the other hand the gearless motor operates at highest efficiency on level track or lesser grades, and it is this class of service that constitutes the bulk of the all-day duty of a passenger locomotive.

A comparison of the efficiencies of the present geared locomotive of the St. Paul road with those of the gearless locomotive under construction is presented in Fig. 4. For convenience the curve is plotted with speed as abscissæ, instead of the usual method of plotting efficiency to ampere input. A comparison of the two curves is most instructive. The average operating speed at about 50 m.p.h. shows a gain of 10 per cent in efficiency of the gearless locomotive as compared with the geared type; and in fact throughout the entire range of speed from thirty miles up the gearless locomotive will operate at over 90 per cent efficiency, as compared with drooping characteristic of the geared motor locomotive.

Electrical apparatus is inherently so efficient in its conversion of electrical into mechanical power that there is usually little gain in going from one type of motor to the other. It is, therefore, proper to note that the considerable gain in efficiency resulting from the adoption of the gearless motor is due almost entirely to the elimination of the mechanical losses inherent with geared motor drive. The exclusion of mechanical parts, such as gears, quills, jack-shafts, side rods, etc., utilized to transmit the power from the motors to the drivers with some forms of locomotive construction not only results in a marked improvement in the all-day efficiency of the locomotive, but is followed by an equally attractive increase in reliability and a marked reduction in maintenance expense. It is felt, therefore, that the introduction of the gearless locomotive upon the Chicago, Milwaukee & St. Paul marks a distinct advance in electric railroading and that this type of construction now for the first time made possible for mountain service will result in a marked improvement in the method of handling both passenger and freight trains in this most difficult class of railroad service.

Fig. 6. Wheels and Armature of Bipolar Gearless Motor

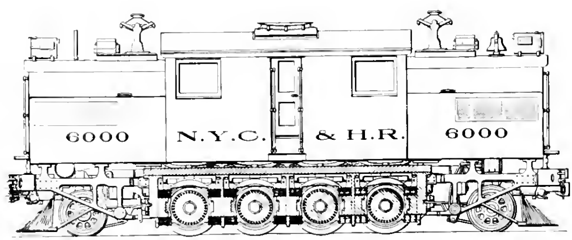


Fig. 7. Latest Type New York Central Locomotive Equipped with Eight Bipolar Gearless Motors

Ventilation System for Steam Turbine Alternators

PART II. OPERATION OF VENTILATING SYSTEMS

By E. KNOWLTON and E. H. FREIBURGHOUSE

ALTERNATING CURRENT ENGINEERING DEPARTMENT, GENERAL ELECTRIC COMPANY

The previous installment of this article dealt with the design of the ventilating system. The effect of dirt in the ducts on the temperature of the generator was shown by the results of tests on machines in service; these tests illustrating very forcibly the desirability of installing an air washer, which functions to both clean the air and reduce its temperature. The present installment discusses the cause of moisture condensation on the internal parts of the generator and the means of preventing this troublesome condition. The causes of moisture condensation are not fully understood by some central station operators, and this article will be of great assistance in making this important matter clear.—EDITOR.

Temperature of Ingoing Air

The temperature of the armature windings should not be so low that the insulation is brittle, since when in that condition a slight bending of the ends of the coils caused by a short circuit may crack the insulation. The temperature of the ingoing air should not be lower than 0 deg. C. if adjustment of dampers can prevent it. If the ventilating system is such that air greatly below 0 deg. C. must be taken in, the quantity should be reduced to an amount that will allow of a proper temperature of the armature winding.

If the temperature measuring devices are placed in the core portion of the armature winding the supply of air should be so adjusted that these record a temperature from 50 deg. to 65 deg. C. The ends of the winding outside of the core will be from 15 deg. to 25 deg. C. lower than these values, and the insulation will be in a pliable condition.

Deposition of Moisture on Windings and Leads

The concentration of large amounts of power in one room and the necessity of having entrance and exit ducts for the ventilating system has introduced conditions which, though not altogether unknown in other apparatus, require greater consideration in turbo-alternators. The ventilation system of the turbo-generator, if grossly neglected, may be a primary source of trouble in causing the deposition of moisture on the alternator leads and windings. However, by correctly utilizing this ventilation system, the machine may be operated with safety from moisture, at the same time relieving station conditions where moisture is precipitated under station roofs.

The writers have had the opportunity to become acquainted with a number of cases of this nature and to make a few tests. The experience, while not extensive, is sufficient when supplemented with the theoretical knowledge of the properties of air (and water vapor) to show what practices should be avoided to prevent this trouble.

Moisture Characteristics of Air

The atmosphere always contains some water vapor, the amount of which is constantly changing. The *maximum* quantity of water vapor which can exist in a given volume of air is dependent only upon its temperature. When air contains this quantity of water vapor it is said to be saturated. The relation between the weight of water vapor in 1000 cu. ft. of saturated air and the

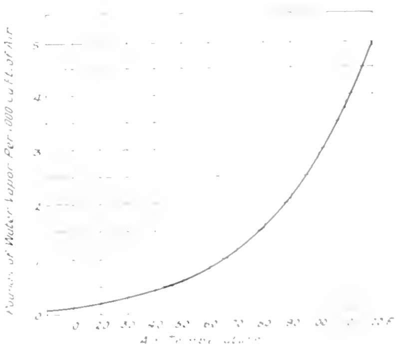


Fig. 6. Weight of Water in Saturated Air at Various Temperatures

temperature of the air is shown in Fig. 6. Air may and usually does contain a lesser quantity of water vapor than is required to saturate it at the existing temperature, this condition being caused by the great variation of vapor pressure with temperature

Relative Humidity

The relative humidity is the amount of water vapor in a quantity of air, expressed in per cent of saturation. Saturated air has a relative humidity of 100 per cent

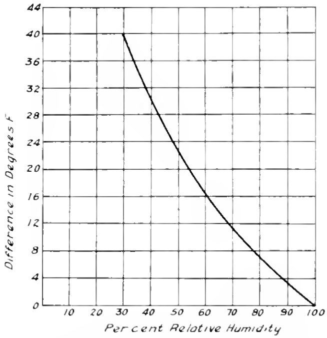


Fig. 7. Difference in Degrees Fahrenheit Between the Dry Bulb and Dew Point Temperatures as Function of the Relative Humidity

The Absolute Humidity

The absolute humidity is the weight of water vapor in a given quantity of air. It is usually expressed in grains per cubic foot of air, but in this article it will be stated as the,pounds per 1000 cubic feet of air.

The Dew Point

The dew point is the temperature at which saturation is attained by any mixture of air and water vapor, i.e., the dew point is the temperature at which any further reduction in temperature will cause condensation. The difference between the air temperature and its dew point temperature depends on the relative humidity and is practically independent of the air temperature. In Fig. 7 is given the difference between the dry bulb and dew point temperatures as a function of the relative humidity.

In Table VI are given the mean moisture characteristics of air at 8 a.m. and 8 p.m. for the year 1905, for several of the important cities in the U. S. The table is arranged in the order of the values of relative humidities. It is interesting to compare Bismarck, N. D., with Phœnix, Ariz. Although the relative humidities of the two are 68 per cent and 49.5 per cent, respectively, the absolute humidities are 0.269 and 0.55 pounds per 1000 cubic feet, i.e., the actual quantity of water in the atmosphere of Bismarck, N. D., is only 49 per cent of that at Phœnix, Ariz. The difference between dry bulb and dew point temperatures are 10.5 deg. F. for Bismarck and 24.9 deg. F. for Phœnix

Removal of Water from Air by Lowering Its Temperature

Lowering the temperature of air below its dew point results in condensation of water vapor. Some of the most familiar examples of this phenomena are rain, dew, and the sweating of water pipes. The last column of Table VI gives the pounds of water condensed per 1000 cubic feet of air by a drop of 4 deg. F. (22. deg. C.) below the dew point.

TABLE VI

CHARACTERISTICS OF AIR, AVERAGE OF RECORDS TAKEN AT 8 A.M. AND 8 P.M. FOR THE YEAR 1905

	DRY BULB TEMPERATURES		HUMIDITIES			Pounds of water condensed per 1000 cu. ft. of air by a drop of 4 deg. F. 2.2 deg. C below dew. point
	F. Deg.	C Deg.	Relative per cent	Absolute. Pounds of water vapor per 1000 cu. ft. air	Dew Point F. deg.	
Jacksonville, Fla. . .	66.2	19	80.5	.845	59.5	.102
Chicago, Ill.	47.3	8.5	77	.412	40	.056
San Francisco, Cal.	55.4	13	77	.547	47	.07
Albany, N. Y.	46.2	7.9	74	.394	38	.053
New York, N. Y.	50.8	10.4	74	.447	43	.06
Indianapolis, Ind.	50.7	10.4	73	.44	42	.059
San Antonio, Tex.	66.2	19	70.5	.716	55	.091
Boston, Mass.	48.1	8.9	69	.386	38.5	.051
Bismarck, N. D.	39	3.9	68	.269	28.5	.041
Phœnix, Ariz.	68.9	20.5	49.5	.55	44	.063

Determination of Humidity

The amount of water vapor associated with the air in a given space may be found from steam tables, provided the dew point is known for the volume of vapor in question. Knowing the dry bulb temperature of the air, the barometric pressure and the dew point, we may readily ascertain the vapor pressure, weight of moisture in a cubic foot of air, the relative humidity, and the weight of air in a cubic foot. In the field it is rather difficult to determine the dew point directly. From simultaneous observations of the dew point and the dry bulb and wet bulb temperatures the U. S. Weather Bureau has compiled tables showing the relationship between the temperatures. From these the dew point may be found by readings from the dry and wet bulb thermometers of a psychrometer.

Since the humidity has so important a bearing on some phases of operation, it may be well to describe the method of measuring humidity adopted by the U. S. Weather Bureau.*

Sling Psychrometer. This instrument consists of a pair of thermometers provided with a handle which permits of rapidly whirling them, the bulbs being then strongly affected by the temperature of the air and the quantity of moisture in suspension. The bulb of one thermometer is covered with thin muslin, which is wet at the time an observation is made.

The Wet Bulb. It is important that the muslin covering for the wet bulb be kept in good condition. The evaporation of the water from the muslin always leaves in its meshes a small quantity of solid material, which sooner or later stiffens the muslin so that it does not readily take up water. This will be the case if the muslin does not readily become wet after being dipped in water. On this account it is desirable to use as pure water as possible, and also to renew the muslin from time to time. New muslin should always be washed to remove sizing, etc., before being used. A small rectangular piece wide enough to go about one and one-third times around the bulb, and long enough to cover the bulb and that part of the stem below the metal back, is cut out, thoroughly wetted in clean water, and neatly fitted around the thermometer. It is tied first around the bulb at the top, using a moderately strong thread. A loop of thread to form a knot is next placed around the bottom of the bulb, just where it begins to round off. As the knot is drawn tighter the thread slips off the rounded end of the bulb and neatly stretches the muslin covering with it, at the same time securing the latter at the bottom.

Making an Observation. The so-called wet bulb is thoroughly saturated with water by dipping it into a small cup or wide-mouthed bottle. The thermometers are then whirled rapidly for fifteen or twenty seconds, stopped and quickly read, the wet bulb first. This reading is kept in mind, the psychrometer immediately whirled again and a second reading taken. This is repeated three or four times, or more, if necessary, until at least two successive readings of the wet bulb are found to agree very closely, thereby showing that it has reached its lowest temperature. A minute or more is generally required to secure the correct temperature.

After obtaining the temperatures the relative and absolute humidities may be determined by reference to psychrometer tables in Engineering handbooks, U. S. Weather Bureau Psychrometric Tables, or other sources.

PRECAUTIONS TO BE OBSERVED IN THE OPERATION OF VENTILATING SYSTEMS

Absorption of Water from the Air

Fibrous materials in their natural state readily absorb water from the air. This surface-held water does not cause the object to feel wet and its vapor pressure is not equal to that of liquid water at the same temperature, being lower the smaller the amount of water on a given surface. Experiments at Lowell, Mass. on worsted and cotton yarns showed that the average percentages of water by weight were 17.5 and 8.5 per cent respectively. To overcome this absorption of water, fibrous insulating materials are generally well impregnated and covered with varnishes, and little trouble is experienced with machines in regular operation. Should machines be idle for a long period in a damp atmosphere it is but reasonable to subject them to a drying-out run before being placed in service.

Condensation on External Surfaces of Electrical Machinery

This condition may be said to have the possibility but not the probability of trouble. Machines have been run for considerable periods with the external surfaces wet or frosted without trouble, but the condition is undesirable.

* A sling psychrometer may be easily made by fastening two thermometers to a thin block of wood, allowing the bulbs to extend beyond the end of the block. At the other end a cord may be attached for whirling. This will give as accurate results as the more refined instrument described below.

When air having a temperature considerably below that of the engine room is taken into a machine, the external surfaces of the parts exposed to the air as it first enters may have their temperature reduced below the dew point of the engine room, causing a deposit of water on these surfaces, which, finding its way through the joints to the incoming air, may be carried to the vulnerable parts of the windings. The humidity of the air in the engine room is high owing to unavoidable steam leakage, and its temperature is considerably higher than that of the outside air. Such conditions can readily occur, as is shown by Table VII. Referring to this table, it is seen that an ingoing air temperature of 32 deg. F. would easily reduce the outside surface of the armature shields below the dew point temperature of 73 deg. F. The amount of condensation depends on the difference between the dew point and the surface temperatures, the absolute humidity of the engine room air, the area of the surface, and the velocity of the air over the surfaces. Frost is occasionally seen on the outside surfaces of armature shields. When this happens there must necessarily be surfaces on which water is present. The remedy for external condensation is to increase the temperature of the ingoing air by taking more from the station and less from outside. This change should not be made suddenly, since condensation will then occur for a time on the inside surfaces of the shields. Also due attention should be given to the mixture of air, as mentioned later.

TABLE VII

A CONDITION CAUSING A CONDENSATION OF WATER ON SURFACES EXPOSED TO THE AIR IN THE ENGINE ROOM

Engine Room Air			Air Entering Generator
Temp. F. deg.	Relative Humidity	Dew Point F. deg.	Temp. F. deg.
80	80 per cent	73	32

Improper Mixture of Air

If in cold weather part of the air is taken from outside and part from inside the station, the relations of temperatures and humidities may be such that the mixture may be supersaturated. When water is produced in this manner it is in a most dangerous form, since fog may be more easily carried through tortuous passages than the coarser spray produced by artificial means. As an example, consider the mixture described in Table VIII.

TABLE VIII

IMPROPER METHOD OF MIXING AIR

	Air from outside of station	Air from station room	Combined mixture
Quantity of air and water vapor in cu. ft.	13,500	13,500	27,300
Temperature in F. deg.	0	80	43.8
Temperature in C. deg.	17.5	26.7	12.1
Relative Humidity per cent	67	75	100
Pounds of dry air	1164	967	2131
Pounds of water vapor	.61	16	12.83
Pounds of water as fog	0	0	3.78

It is to be noted from Table VIII that the combination of air, water vapor, and fog produced from the two sources of air will have, if in stable state, a dry bulb and dew point temperature of 43.8 deg. F., a relative humidity of 100 per cent, a vapor content of 12.83 pounds and will be wet with 3.87 pounds of precipitated moisture or fog.

In case an air washer is not used and evaporation is relied upon for the complete elimination of the fog, the fog will be carried along with the air until sufficient sources of heat have been encountered to raise the temperature to 50.6 deg. F. Before reaching sources of heat some fog would settle out on surfaces coming in contact with the passing air, for instance upon the armature leads, where it would be a potential source of trouble.

The windage losses through the fans would be sufficient to raise the temperature of the mixture approximately 7 deg. F., provided the machine had been in operation a sufficient time to have its internal surfaces warm. However, if the machine has been standing still and conditions have been such that cold air has been allowed to pass through the alternator for several hours, the temperature of the machine parts may be so low that the air initially may not obtain a temperature rise corresponding to all of the fan losses. Then, too, the element of time and non-uniform distribution of the fog may retard the entire evaporation of the fog or water until part of it has been thrown upon the ends of the windings. When using an air washer during winter operation to secure the maximum amount of dehumidification of station air with the least amount of discarded circulating water there will be an advantage in making such mixtures of air as described in Table VIII. The mixture should occur before passing through the air washer, but never permitted between washer and generator.

Reduction in Temperature of the Air After Entering the Generator

The reduction of the air temperature after it enters the machine is not a common occurrence, but has been observed in a few cases. A machine may be idle through part of the day in cold weather, and the air ducts to the machine, if left open, may pass a sufficient quantity of air, due to the natural draft or favorable direction of the wind, to cool the internal parts by a considerable amount. By the time the machine is started the temperature and humidity of the air to be taken in may be such that for a time water will be deposited on the internal surfaces without its presence being suspected. Under the conditions described air taken from the engine room when starting would be more likely to produce this result than air from outside the station. As the machine temperature increases this condition will cease to exist, but the water already deposited in the machine may not be readily evaporated because of a film of dirt on its surface, or from being in a position where the air is comparatively quiet.

This trouble may also occur where two or more generators have air piped to them from a common ventilating chamber which is supplied with air from out-of-doors, the dynamo room, or the basement. For example, assume two units to be piped from the air conditioning room, which is taking the greater part of the air from out-of-doors at a low temperature, and both units delivering air either into the dynamo room or to the boiler room, and that one of the units is then shut down, possibly the air would continue through the generator for a time, causing a fairly low temperature of the windings. If the operator should now shut off some of the air from out-of-doors, allowing the unit which is running to draw its air from the conditioning chamber, the probabilities are that the suction produced in the air conditioning chamber would cause a reversal of the air current in the duct leading to the idle unit, thus drawing through the generator the warmer and moister air of the dynamo room or the boiler room, and causing a condensation on the internal surfaces. Cases of condensation have occurred that could be explained by no other means than a reversal of air current.

Moisture on Armature Lead and Cable Joints

It is not on the windings alone that the condensation of water is objectionable. The joint between the armature leads and the cables is often in the air path, and if the joint is imperfectly insulated, or if deterioration is allowed, the water may cause a short circuit.

Condensation on Engine Room Ceilings

Condensation on the ceilings of engine rooms frequently occurs during cold weather to such an extent that water drops to the floor and upon the alternator. If the air discharge from the generator is upward into the room the water may easily reach the windings. If this is allowed for several hours, while the machine is idle, a considerable quantity of water may collect.

In Fig. 1 (Part I) is shown in dotted lines an intake air duct the upper end of which is extended to a point near the ceiling. The object of this is to provide a means of reducing the humidity of the engine room air. To accomplish this an air washer should be provided and operated with a continuous *external* supply of water, at a temperature as much below the dew point temperature of the engine room as possible. The ingoing air will then have its temperature considerably reduced in passing through the washer, and, although it will leave saturated, the quantity of water will be less than when it entered, owing to the lower temperature. That is, under these conditions the washer acts as a de-humidifier, thereby reducing the possibility of condensation on the engine room ceiling. Establishing a more rapid circulation of air over the ceiling will in itself be beneficial, as this will raise the temperature of the surface and of the air in actual contact with the surface. With this arrangement the quantity of air admitted to the engine room from outside should be as small as is consistent with safe operating temperatures, and it should be admitted near the engine room floor. The efficiency of this method depends largely on the thermal resistance of the roof, the quantity of steam leakage in the turbine room, and the temperature outside the station. There is no doubt that considerable improvement may be obtained, but it may not be possible to entirely prevent condensation when all of the factors are extremely severe.

This de-humidifying action cannot occur if the water is circulated in the washer in the usual manner, for the water is then at the wet bulb temperature of the air, and none of the water vapor in the air can be condensed.

Air Washers

A properly designed and operated air washer will permit no drops of water to pass through it, and the means of discovering this defect are so simple that it need not exist unknown.

Several conditions which allow the passage of water are:

(a) Too small a washer for the duty.
(b) Too high a pressure on the nozzles.
(c) Deterioration of the eliminator plates.

The presence of water may be easily determined by holding a glass plate about two feet from the exit end of the eliminator for several minutes and noting whether water is deposited thereon. The temperature of the plate when inserted should be slightly above that of the air leaving the washer to prevent condensation. With a new washer this test should be made in a number of positions transversely several times each day for the first week. Thereafter the test should be repeated weekly. A permanent installation of a glass plate set at an angle with a light and sight hole in the duct is a convenient arrangement and may be employed to determine if the washer is operating properly. The same device is useful when no washer is employed to detect the presence of water from any cause.

If air enters an air washer at 75 deg. F. (23.9 deg. C.) with a relative humidity of 74 per cent the amount of water used for spraying when recirculated will be approximately 500 times the amount evaporated and 50 times the amount which enters the washer with the air.

Air having a temperature nearly down to the freezing point should not be admitted to an air washer because of the danger of coating the eliminator plates with ice and reducing the quantity of air. If the air temperature is several degrees above the freezing point the evaporation in the washer might be sufficient to lower it to the freezing point. The fine spray and the many eliminator plates form a combination whereby a sheet of ice could be readily formed, shutting off a large portion or even all of the entering air.

It is obvious that the vapor condition of the air entering the washer can have but little effect on the humidity of the air leaving the washer. In other words, the air leaving will be practically saturated, having no free moisture, and its temperature will be the temperature of the water in the washer. If this water is circulated in the washer as is usual its temperature will be the same as the wet bulb temperature of the entering air. Assuming this latter method of operaing the washer:

TABLE IX

	AIR ENTERING DIRTY			AIR LEAVING CLEAN		
	Temperatures		Rel. Hum.	Temperatures		Rel. Hum.
	Bulb Dry F.deg	Bulb Wet F.deg	Per Cent	Bulb Dry F.deg	Bulb Wet F.deg	Per cent
A	120	80	30	80	80	100
B	80	80	100	80	80	100
C	80	80	100 plus fog	80	80	100 no fog

the results of washing three varieties of air are given in Table IX, the only point in common being the wet bulb temperature of 80 deg. F. Sample A is a hot dry air, sample B a lower temperature of fully saturated air, and sample C similar to B but carrying fog to the extent of 0.15 lb. per 1000 cu. ft. In all cases the quality of the leaving samples is identical. The use of an air washer eliminates most of the undesirable features mentioned in the preceding sections and its installation should be more general.

Moisture in Other than Steam Turbine Stations

The high temperatures and humidities of steam turbine engine rooms tend to questionable ventilating conditions, but other stations are not immune from this trouble. Precautions should be taken whenever there is possibility of a marked reduction in the temperature of the air surrounding an electrical machine or entering it.

Summary of Moisture Prevention Measures

A careful reading of this article will show that the essential feature of moisture prevention is the avoidance of a reduction in the temperature of the air at any point in the ventilating system where water is objectionable. It is not expected that more than a part of the undesirable methods of operation have been described, but the criterion of proper operation is that mentioned above. Each power station should study their ventilating conditions with reference to the principles stated. Special attention is necessary in the colder months of the year, since it is then that greater differences exist between the indoor and outdoor air, and considerable reductions in air temperatures may occur.

Methods for More Efficiently Utilizing Our Fuel Resources

Part XVII. THE EXTENT OF THE USE OF PULVERIZED FUEL IN THE INDUSTRIES AND ITS POSSIBILITIES IN THE WAR

By E. P. Coffin

Research Laboratory, General Electric Company

The following article is presented in two sections: The first section briefly summarizes the advantages of pulverized coal, treats of the suitability of its use as fuel for stationary boilers, locomotives, steamships, and metallurgical furnaces, and recommends its adoption to conserve our coal resources and to release for military use the fuel oil now burned for industrial purposes. Following a description of the indispensable part that electric power plays in the preparation, handling, and burning of pulverized fuel, the second section of the article presents an impressive list of the American users of pulverized fuel.—Editor.

GENERAL ADVANTAGES OF PULVERIZED FUEL

1. Flexibility of control of fuel and air, and ability to extinguish the fire instantly.

2. Complete combustion, even at high rates of burning, and elimination of smoke; assuming, of course, that the installation is properly made and operated.

3. Burning fuel in suspension eliminates the usual troubles which result from the formation of clinkers in the fire bed when coal is burned on grates.

4. Low-grade fuels may be burned efficiently regardless of the proportion of ash, sulphur, or other impurities. When low-grade fuels are burned on grates, the capacity of the furnace is reduced in proportion to the percentage of combustible content. This limitation does not hold when burning pulverized fuel in suspension, as the amount of ash in suspension in the flame at any one time is inconsiderable.

5. Very little excess air is required. This reduces the stack loss as well as the power required for the draught blowers. Also, less area is required in flues and stacks.

6. Maximum fuel economy is possible in many applications.

7. The expense of supplying coal to scattered industrial furnaces is thereby reduced to a minimum. Pulverized fuel has semifluid properties; it flows easily and can be transferred through pipes:

(a) By screw conveyors.
(b) In a mass by means of compressed air.
(c) In suspension in a current of air.

APPLICATION OF PULVERIZED FUEL TO INDUSTRIAL FURNACES

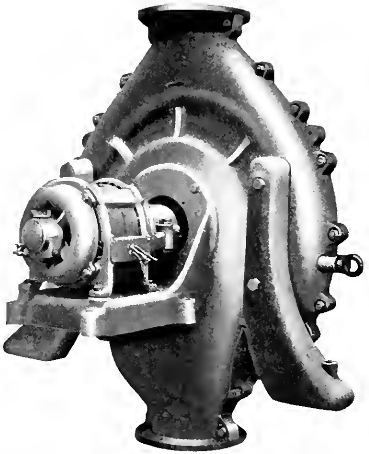
Pulverized coal was first utilized in the United States about twenty-six years ago, for economically burning cement rock in the rotary kilns of the Portland cement industry. It has now largely replaced more expensive fuels, such as oil, in parts of the country where coal is readily obtainable.

Calcining Kilns

The rotary cement kiln fired with pulverized coal has been applied in several other industries, as for calcining various minerals. (Calcining is a term used synonymously with burning, where the process involves the driving off of carbon-dioxide gas or of water of crystallization.)

The Pulverizers, which are grinding cement rock in this installation, are of a type most commonly used for pulverizing coal

Furnace refractories are made by calcining dolomite and magnesite. Lime is burned for making calcium carbide, and for use in open-hearth furnaces. Gypsum is calcined for making plaster of paris and stucco by driving off the water of crystallization.



Single-stage Centrifugal Air Compressor with capacity of 3300 cubic feet per min. at 1 lb. per square inch pressure. Machines of this type are in use for blowing pulverized coal into open hearth steel furnaces

Potash is extracted from alunite, sericite, greensand, and marl, and is produced as a by-product of the Portland cement industry. It is distilled from the cement rock under treatment in the kilns and sublimes in the form of fine dust which goes up the flue. In some cement plants the flue dust is recovered by the Cottrell electrostatic precipitation process. This flue dust contains a large percentage of potash and is used for fertilizer purposes.

Dryers

Pulverized coal is used for drying cement rock before feeding it to the kilns, and it has been used to a small extent for firing rotary coal dryers in pulverizing plants. One plant is installing equipment for drying bauxite in a rotary kiln.

In the fertilizer industry it is used for drying tankage (garbage and sewage), for drying and slightly roasting phosphate rock, and for drying feldspar shale in rotary kilns for use as fertilizer filler.

Metallurgical Furnaces

The most important application in which pulverized coal has made notable progress in the last few years is in the metallurgical field. Marked economies have been attained by the application of this fuel to furnaces used in the manufacture of iron, steel, copper, zinc, galvanized iron, and tin plate.

The application of pulverized coal in the metallurgical industries is still in its infancy, but the list of plants using it shows that it has made good progress.

The shortage of natural gas in some localities has been an incentive for the greater use of pulverized coal, and the high cost of fuel oil has been an additional incentive.

On the average, the substitution of pulverized coal as a fuel for metallurgical furnaces has resulted in a saving of about 33 per cent of the fuel required when burning coal in other ways.

One feature of interest in this connection is a comparison of the percentage of excess air required when burning various fuels in metallurgical work.

TABLE I

Pulverized coal	5 to 25 per cent
Hand-fired coal	100 to 125 per cent
Stoker-fired coal	50 to 100 per cent
Producer gas	50 to 75 per cent
Natural gas	40 to 50 per cent
Fuel oil	50 per cent and upward

Ore Roasting and Nodulizing

In the manufacture of sulphuric acid, iron pyrites is burned in special furnaces to sulphur dioxide and pyrites clinker. The latter is an oxide of iron containing about 2 per cent of sulphur, the original content being 48 per cent or more.

This 2 per cent sulphur content is too high for smelting the pyrites clinker as an ore of iron; also, it contains a large proportion of fine dust. It is, therefore, treated in nodulizing kilns of the rotary cement type which are fired with pulverized coal. The nodulizing operation consists of roasting off the residual sulphur and fusing the dust into nodules which can be smelted for making iron. Flue dust is also nodulized, thus making available products which have heretofore been rather expensive to recover.

APPLICATION OF PULVERIZED FUEL TO STEAM BOILERS

The field of steam generation may be subdivided into three classes: stationary boilers, locomotives, and steamships.

Stationary Boilers

The high efficiency obtainable with modern stokers has rendered the introduction of pulverized fuel for boiler firing less attractive, at first sight, than in the case of industrial furnaces. The development of the underfeed stoker has forestalled pulverized fuel in this field so that the latter has a more difficult road to travel. Many engineers regard pulverized coal as the ideal fuel, but the additional machinery required for its preparation seems a handicap and renders it difficult to make the plant as compact. It is claimed, however, that large new plants can be equipped for the preparation and burning of pulverized fuel at less cost than for burning coal on stokers.

It should also be considered where hand firing is to be superseded, or where old stoker equipment is to be replaced, and especially where low-grade coal is to be burned. In some cases the capacity of an old plant may be increased by firing the existing boilers with pulverized coal, owing to limitations in the size of flues and stacks. The smaller amount of excess air required is then an important factor.

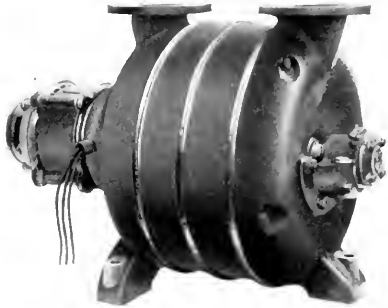
The elimination of clinker troubles is an important advantage when poor coal is being burned. Some old boilers are mounted so close together that there is no room to get in at the sides with a bar for breaking up clinkers, which is necessary when substituting underfeed stokers.

Waste-heat boilers are installed in connection with many furnaces and kilns to save the heat which would otherwise be lost in the flue gases.

Locomotives

On locomotives and steamships hand firing still persists owing to the difficulty of making satisfactory stokers to operate within the limited space available.

The steaming capacity of large locomotives is often seriously limited by the inability of the firemen to shovel coal fast enough to maintain full steam pressure, and by the continual opening of the fire door which disturbs uniform draught. In the western states, where only poor grades of coal are available, this difficulty with hand firing has often led to the substitution of oil-burning engines on mountain grades. In this service it is difficult to burn oil efficiently when forcing the boilers. Pulverized coal has the same advantages as fuel oil in locomotive service in regard to stoking and, in addition,



Small Three-stage Centrifugal Air Compressor with capacity of 250 to 350 cubic feet per minute at $1\frac{1}{2}$ lb. per square inch. This type of machine can supply the primary air to pulverized coal burners at any pressure from one-half lb. to $3\frac{1}{2}$ lb. per square inch, by varying the number of stages from 1 to 6. The power required is from 2 to 8.5 h.p.

efficient combustion can be maintained at high rates of burning.

Several American railroads have been experimenting with pulverized fuel on locomotives and when the various preliminaries are completed, in the way of constructing pulverizing plants, some of them will begin using it on a commercial scale.

Pulverized fuel is already being used on a commercial scale on locomotives in two foreign countries. The Central Railway of Brazil has twelve locomotives operating with Brazilian coal and American equipment. This coal has such a high sulphur content that it has not been successfully burned in any other way. Brazil has always imported it's coal heretofore, although enormous deposits of native coal are available. Additional locomotives are now being equipped.

One line of the Swedish government railways, 60 miles in length, is being operated with locomotives burning peat powder. This is burned in suspension in the combusiton air similarly to pulverized coal. The develonment work was carried on by the Swedish government with a view to replacing imported coal.

Steamships

Fuel oil has made considerable headway in displacing coal, both in the merchant marine and in the navies of several countries, in spite of its high cost in some parts of the world. Its advantages over hand-fired coal are:

1*m* Saving of stokehold labor.

2 Fuel handling is reduced to the simple operation of pumping oil through pipes. This applies both to oiling the ship and to feeding the burners from tanks located in any part of the vessel.

3 Cleanliness.

4 Low fireroom temperature.

5 Higher calorific value.

6 Higher efficiency in boiler firing.

7 Ability to operate boilers at a higher rating.

8*m* Ability to force boilers instantly when an attack demands a sudden increase of speed.

9*m* Smokeless combustion.

10*m* Ability to work up a smoke screen instantly by overfeeding fuel.

The four advantages marked (*m*) are of especial military value. By establishing pulverizing plants at ports, coaling stations, or on board naval colliers, pulverized coal could be used on ships with practically all the listed advantages over hand-fired coal, except (5). More tons of coal must be carried than is the case with oil owing to the high calorific value of oil. However, pulverized coal is burned with better efficiency than hand-fired coal, and this fact will partly offset this disadvantage. Oil is burned on shipboard with at least 12 per cent better efficiency than hand-fired coal, and the same should be true with pulverized coal.

Pulverized coal when stored in strong tanks along the sides of a ship presents considerable possibilities in the way of torpedo protection.* The U. S. Shipping Board has recently authorized the building of a large steamship embodying this idea and using pulverized coal as fuel.

The Necessity for the Conservation of Fuel Oil

The building of so many oil-burning ships, together with the loss of many oil tankers through the operation of German submarines, raises a serious problem in regard to the supply of fuel oil in adequate quantities.

* Hudson Maxim, *Scientific American*, March 30, 1918.

The production of fuel oil in the United States, as well as the facilities for its transportation, are inadequate to meet the demands. Only about 10,000 tank cars are available on our railroads and the oil pipe lines are already working at their maximum capacity.

There is a large source of oil available in Mexico but we must build new tank steamers to transport it. The greater part of Mexico's output has come from two wells. This naturally renders the supply uncertain, for oil wells are subject to accidents or fires; besides which this source of supply is not under our control and is in danger of possible interference.

Oil is such a valuable fuel in our industries that it can only be spared if equally practical and efficient fuels are available as substitutes. It is doubtful if fuel oil can be entirely replaced, except by expensive gaseous fuels. Pulverized coal is the most economical substitute for many purposes and is much cheaper than fuel oil at the present prices.

The further industrial application of pulverized coal should release fuel oil for the use of the great fleet now building for the American merchant marine, and for the navy.

This appears to be the most immediately available method of alleviating the situation, but it will not be adequate to release all the oil that will be required.

Pulverized Coal for Ocean Transport Service

It is very evident, therefore, that the most effective method of dealing with this phase of the fuel situation is to immediately attack the problem of utilizing pulverized coal on board ship. Like all new developments, this is a problem in which it will take time to work out details in connection with the initial installations, before it can be applied on a large scale.

Pulverizing stations will have to be established at several of our leading ports. As the greater part of our exports to Europe are shipped from Boston, New York, Philadelphia, Baltimore, and Newport News, it will be sufficient to establish pulverizing stations at these five ports where ships may be coaled for the round trip. Commerce from other ports can be carried in ships burning oil or ordinary coal.

The slight disadvantage of limiting a ship to certain ports may be overcome by installing equipment for burning oil as an emergency fuel to enable the ship to complete a voyage from some other port to her home port. Oil may be carried in the double bottom where it will be independent of the coal storage and handling equipment. The same compartments may also be used for shipping oil to Europe as cargo.

ELECTRIC POWER USED FOR THE PREPARATION AND HANDLING OF PULVERIZED FUEL

Electric power is probably used more extensively in the preparation and handling of pulverized fuel, on the basis of kilowatt-hours per ton, than is the case with any other form of fuel. One possible exception is briquetted fuel. In this country, however, the amount of fuel briquetted is very small.

Electric power is used for the following operations in connection with pulverized fuel:

- Crushing the coal to 1-inch size or less.
- Energizing magnetic separators.
- Rotating the dryer drums.
- Pulverizing the coal.
- Elevating lump coal and pulverized coal.
- Driving screw conveyors.
- Driving feed screws for burners.
- Driving reciprocating air compressors for high-pressure air, transport systems, and blast feed to burners.
- Driving centrifugal air compressors for supplying air for combustion at a pressure of about 1 lb. per sq. in.
- Driving low-pressure blowers for supplying air for combustion at lower pressures, and for conveying coal in suspension through pipes; also for separating the finished product from the unfinished in pulverizing.

No one plant uses power for all of these items as the list includes the component parts of several different systems for preparing and handling pulverized coal.

The amount of pulverized fuel used annually in the United States at the present time is about ten million tons, divided by industries approximately as follows:*

- Manufacture of cement, six million tons.
- Iron and steel industry, two million tons.
- Production of copper, one and one-half million tons.
- Generation of power, one hundred to two hundred thousand tons.

The power requirements of one representative system of preparing, conveying, and burning pulverized coal are about 35 h.p. hr. per ton. With a motor efficiency of 89 per cent, this corresponds to a power consumption of 29.4 kw-hr. per ton.

Some systems will require less power and others more, according to the methods used in pulverizing and conveying. Air transport systems require more power for their operation than mechanical systems, but have the advantage of greater simplicity and flexibility. Assuming an average consumption of 30 kw-hr. per ton, for the ten million tons used, the yearly power requirements will be 300 million kw-hr.

As many of the furnaces using pulverized coal have to operate fairly continuously, we will assume an average yearly operation of 5000 hours out of 8760. At this load-factor, the average power consumption will be 60,000 kilowatts.

If 2.5 lb. of coal are consumed in the power station per kw-hr. this corresponds to 375,000 tons yearly for preparing and handling 10,000,000, or 3.75 per cent of the total.

When burning other fuels there will be a corresponding charge which will vary according to the fuel and the method of firing. When atomizing oil with a steam jet, the amount of steam consumed is from two to three per cent of the total steam generated in an oil-fired boiler. In addition, power is required for pumping the oil and for the blowers which maintain the air blast. This is an extravagant way of burning oil, but requires the least equipment. Pumping oil through mechanical atomizers is a more efficient method of burning.

In power stations the stokers require power for actuating the fuel feed, and for the undergrate air-blast. In addition, power is required for crushing and conveying the coal. With pulverized fuel the combustion is more complete and the stack loss is reduced. The result is that the net efficiency is a little better with pulverized coal under test conditions; and taking the human factor into consideration, it should be easier to maintain operating efficiencies which are more nearly comparable to those attained in test.

It is evident, therefore, that the power charges against the preparation and handling of pulverized coal are offset by the more efficient utilization of the fuel.

By the use of off-peak power for preparing pulverized fuel the comparison can be made still more favorable and a margin provided to absorb other charges, such as labor at the pulverizing plant, when the installation is of sufficient size.

* H. G. Barnhurst, Pulverized Coal and Its Future, GENERAL ELECTRIC REVIEW, February 1918, page 117.

If this be the case where the margin is smallest, it must be more marked in the case of metallurgical furnaces where the fuel saving is greater than is possible in a modern boiler plant.

Considerable fuel economies are possible, however, in boiler plants having old style stokers or where hand-firing can be superseded.

The Steam Turbine Engineer's Point of View

From the point of view of the engineers having to do with the design and development of steam turbines and electrical machinery, it is rather discouraging to see old and wasteful methods of burning fuel persist in the boiler room. They have been gradually bringing the equipment of the generating room up to the highest attainable efficiency by refinements in design and construction. It does not require much in the way of careless firing to nullify their efforts when the overall efficiency of the central station is *the* important consideration in generating electricity from coal.

The underfeed mechanical stoker has much improved the efficiency of the boiler furnace, but it still has its limitations, especially when burning low-grade fuel. With the development of efficient methods of handling and burning pulverized fuel, the power station engineer has another method at his disposal for solving his problems. It may not be universally applicable, in the present state of the art, but it is a great advantage to have two good methods of burning coal under boilers to choose from, each of which has its advantages for certain applications.

The efficient utilization of our low-grade fuels is a matter of ever increasing importance. The re-equipment of old boiler plants for burning pulverized coal may often be more easily accomplished than the installation of efficient stokers, even when good coal is burned.

On shipboard, the steam turbine with mechanical or electrical gearing has much improved the steam economy, and the old-time practice of hand firing should be abolished from the stokehold without further recourse to fuel oil, which is an expensive fuel of limited availability.

PULVERIZED FUEL USERS

The following list of users of pulverized fuel has been compiled by the author from such information as is available at the present time. American-made equipment is used in all of these installations:

STEAM GENERATION

Stationary Boilers

American Locomotive Co.	Schenectady, N. Y.
[2]Anaconda Copper mining Co.	Anaconda, Mont.
[1]Armstrong-Whitworth Co.	Montreal, Quebec
Ash Grove Portland Cement Company	Chanute, Kansas
Central Railway of Brazil	Barra do Pirahy, Brazil, S. A.
Choctaw Portland Cem. Co.	Hartshorne, Okla.
Hudson Coal Company	Olyphant, Pa
[1]Lackawanna Coal Co.	Lichen, Pa.
[1,2]Lima Locomotive Works, Inc.	Lima, Ohio
[1]Milwaukee Elec. Rwy. & Lt. Co.	Milwaukee, Wis.
Missouri, Kan. & Tex. Rwy.	Parsons, Kan.
Pacific Coast Coal Co.	Renton, Wash.
[1]Puget Sound Trac. Lt. & Pwr. Co.	Seattle, Wash.
[2]Sizer Forge Co.	Buffalo, N. Y.
United Verde Extension Mining Co.	Jerome, Ariz.

Steam Locomotives[3]

Atchison, Topeka & Santa Fe Rwy.	Fort Madison, Iowa
[4]Central Railway of Brazil	Barra do Pirahy, Brazil, S. A.
Chicago & Northwestern Rwy.	Chicago, Ill.
Delaware & Hudson Co.	Carbondale, Pa.
Missouri, Kan. & Tex. Rwy.	Parsons, Kan.
New York Central Railroad	Albany, N. Y.

Steamships

[5]United States Shipping Board

METALLURGICAL INDUSTRIES

Open-hearth Furnaces

American Rolling Mills Co.	Middletown, Ohio
American Steel Foundries	Sharon, Pa.
American Steel & Wire Co.	Donora, Pa.
Atlantic Steel Co.	Atlanta, Ga.
[1]Armstrong-Whitworth Co.	Montreal, Quebec
Bethlehem Steel Co.	Lebanon, Pa.
Carnegie Steel Co.	Clairton, Pa.
Carnegie Steel Co.	Homestead, Pa.
Carnegie Steel Co.	Sharon, Pa.
Eastern Steel Co.	Pottsville, Pa.
[1]Follansbee Brothers	Follansbee, W. Va.
National Malleable Cast. Co.	Cleveland, Ohio
National Malleable Cast. Co.	Melrose Park, Ill.
National Malleable Cast. Co.	Sharon, Pa.
Sharon Steel Hoop Co.	Sharon, Pa.

Bushelling and Puddling Furnaces

Bethlehem Steel Co.	Lebanon, Pa.
Burden Iron Co.	Troy, N. Y.
Fort Wayne Rolling Mill Co.	Fort Wayne, Ind.
London Rolling Mills	London, Ont.
Milton Manufacturing Co.	Milton, Pa.
Scranton Bolt & Nut Co.	Scranton, Pa.
St. Louis Screw Co.	St. Louis, Mo.
Union Rolling Mills	Cleveland, Ohio

Continuous Heating Furnaces for Blooms and Billets

[1]Allegheny Steel Co.	Brackenridge, Pa.
American Steel & Wire Co.	Cleveland, Ohio

Bethlehem Steel Co.	Steelton, Pa.
Carnegie Steel Co.	Clairton, Pa.
Dilworth-Porter Co., Inc.	Pittsburgh, Pa.
Midvale Steel Co.	Philadelphia, Pa.
National Pressed Steel Co.	Massillon, Ohio
Oliver Iron & Steel Co.	Pittsburgh, Pa.
Union Rolling Mills Co.	Cleveland, Ohio
Upson Nut Co.	Cleveland, Ohio

Furnaces for Heating, Re-heating, and Forging

American Locomotive Co.	Schenectady, N. Y.
Bethlehem Steel Co.	Lebanon, Pa.
Burden Iron Co.	Troy, N. Y.
A. M. Byers Co.	Pittsburgh, Pa.
Calumet Steel Co.	Chicago Heights, Ill.
Carnegie Steel Co.	Sharon, Pa.
Carnegie Steel Co.	Youngstown, Ohio
Dilworth-Porter Co., Inc.	Pittsburgh, Pa.
E. Dulieux	New York City
Eastern Steel Co.	Pottsville, Pa.
[1]Follensbee Brothers	Follensbee, W. Va.
Fort Wayne Rolling Mill Co.	Fort Wayne, Ind.
[1]Hubbard & Co.	Pittsburgh, Pa.
Inland Steel Co.	Chicago, Ill.
Lima Locomotive Works, Inc.	Lima, Ohio
Middletown Car Co.	Middletown, Ohio
Midvale Steel Co.	Philadelphia, Pa.
Milton Manufacturing Co.	Milton, Pa.
[1]Newport Rolling Mill Co.	Newport, Ky.
Oliver Iron & Steel Co.	Pittsburgh, Pa.
Scranton Bolt & Nut Co.	Scranton, Pa.
Scranton Forging Co.	Scranton, Pa.
Sizer Forge Co.	Buffalo, N. Y.
Standard Steel Works	Burnham, Pa.
St. Louis Screw Co.	St. Louis, Mo.
United States Horseshoe Co.	Erie, Pa.
United States Horseshoe Co.	Manitoba, Canada
[1]Verona Tool Co.	Pittsburgh, Pa.
[1]Warwood Tool Co.	Warwood, W. Va.
[1]Wood, Allan, Iron & Steel Co.	Conshohocken, Pa.

Annealing Furnaces for Malleable Iron & Steel Castings and Plates

American Radiator Co.	Buffalo, N. Y.
Erie Malleable Iron Co.	Erie, Pa.
[1]Establishments Lemoine	Paris, France
[1]Follensbee Brothers	Follensbee, W. Va.
General Electric Co.	Erie, Pa.
Globe Seamless Steel Tubes Co.	Milwaukee, Wis.
International Harvester Co.	Chicago, Ill (Deering Works)
International Harvester Co.	Chicago, Ill. (McCormick Wks.)
International Harvester Co.	Hamilton, Ont.
Kalamazoo Malleable Iron Co.	Kalamazoo, Mich.
Lima Locomotive Works, Inc.	Lima, Ohio
National Malleable Cast. Co.	Cleveland, Ohio
National Malleable Cast. Co.	Sharon, Pa.
[1]Newport Rolling Mill Co.	Newport, Ky.
Pittsburgh Malleable Iron Co.	Pittsburgh, Pa.
Pressed Steel Car Co.	Pittsburgh, Pa.
T. H. Symington Co.	Rochester, N. Y.

Sheet and Pair[6] and Annealing Furnaces, and Tin Pots

[1]American Rolling Mills Co.	Middletown, Ohio
[1]Carnahan Tin Plate & Sheet Steel Co.	Canton, Ohio
[1]Follensbee Brothers	Follensbee, W. Va.
[1]Liberty Steel Co.	Warren, Ohio
[1]Mansfield Sheet & Tin Plate Co.	Mansfield, Ohio
[1]McKeesport Tin Plate Co.	McKeesport, Pa.
[1]Newport Rolling Mill Co.	Newport, Ky.
Phillips' Sheet & Tin Plate Co.	Clarksburg, W. Va.
Standard Tin Plate Co.	Canonsburg, Pa.
[1]Trumbull Steel Co.	Warren, Ohio

Galvanizing Pots

A. M. Byers Co.	Pittsburgh, Pa.
[1]De Forest Sheet & Tin Plate Co.	Niles, O.
[1]Follensbee Brothers	Follensbee, W. Va.
[1]Newport Rolling Mill Co.	Newport, Ky.

Soaking Pits

[1]Atlantic Steel Co.	Atlanta, Ga.

Ore Roasting and Nodulizing

Algoma Steel Corporation	Sault St. Marie, Ont.
Bethlehem Steel Co.	Lebanon, Pa.
Carolina Ore Co.	Winston-Salem, N. C.
Central Iron & Coal Co.	Hold, Ala.
Charleston Ore Co.	Charleston, S. C.
Eastern Nodulizing Works	Newark, N. J.
General Chemical Co.	
International Nickel Co.	Copper Cliff, Ont.
Lackawanna Steel Co.	Buffalo, N. Y.
Mississippi Valley Iron Co.	Waukon, Iowa
Northern Iron Works	Standish, N. Y.
Pennsylvania Salt Mfg. Co.	Natrona, Pa.
Pennsylvania Salt Mfg. Co.	Philadelphia, Pa.
Princess Furnace Co.	Glen Wilton, Va.
Spanish-American Iron Co.	Cuba
Virginia Coal & Coke Co.	Middleboro, Ky.

Copper Ore Roasting and Smelting

American Smelting & Ref. Co.	Garfield, Utah
[1]American Smelting & Ref. Co.	Hayden, Ariz.
American Smelting & Ref. Co.	Maurer, N. J.
[1]American Smelting & Ref. Co.	Tacoma, Wash.
American Smelting & Ref. Co.	Mexico
Anaconda Copper Mining Co.	Anaconda, Mont.
Anaconda Copper Mining Co.	Great Falls, Mont.
Braden Copper Co.	Valparaiso, Chile
Canadian Copper Co.	Copper Cliff, Ont.
[1]Furukawa Mining Co.	Tokyo, Japan
Lake Superior Smelting Co.	Dollar Bay, Mich.
Nevada Cons. Copper Co.	McGill, Nev.
River Smelting & Ref. Co.	Florence, Colo.
[1]United Verde Copper Co.	Clarkdale, Ariz.
United Verde Ex. Mining Co.	Jerome, Ariz.

Zinc Industry

Bartlesville Zinc Co.	Collinsville, Okla.
Edgar Zinc Co.	[illegible], Kan.
River Smelting & Ref. Co.	Florence, Colo.
Société des Mines [illegible] Rossas	Paris, [illegible]

Gold and Silver Industries

[illegible] Gold Mining Co.	[illegible]
[1]River Smelting & Ref. Co.	Florence, Colo.

CHEMICAL AND OTHER INDUSTRIES

Cement Kilns

Summary of Portland Cement Kiln Fuels in 1916

	No. of Plants	No. of Kilns	Barrels of Cement	Percentage of total
Coal	87	643	74,844,603	81.8
Coal and Oil	2	32	4,948,917	5.4
Coal, Oil and Gas	1	5	914,531	1.0
Coal and Gas...	1	7	697,410	.8
Oil...............	17	96	8,041,026	8.8
Oil and Gas......	2	13	957,797	1.0
Producer Gas...	1	1	76,951	0.1
Natural Gas.....	2	10	1,039,963	1.1
	110	807	91,521,198	100.0

All the coal used is burned in pulverized form.

The plants using fuel oil are located in the states where oil is the principal regional fuel, such as, Washington, Oregon, California, Arizona, and Texas. These five states contain 21 cement plants, while only 18 plants use oil, either wholly or in part. Some foreign plants also have American pulverized-fuel equipment.

Calcining Kilns

Gypsum Rotaries and Kettles

Manitoba Gypsum Co. Winnipeg, Man.
Niagara Gypsum Co.... Oakfield, N. Y.
Plymouth Gypsum Co. . Fort Dodge, Iowa

Lime Burning

[1]Air Nitrates Co. Sheffield, Ala.
Bare Paper Co. (Lime Sludge) Roaring Springs, Pa.
Campbell Stone Co. Afton, Mich.
Industrial Limestone Co. .. Nazareth, Pa.
Lackawanna Steel Co..... Buffalo, N. Y.
[9]Solvay Process Co. ..Syracuse, N. Y.
Tennessee Coal, Iron & Railroad Co.. . Birmingham, Ala.
Union Carbide Co.. ....Niagara Falls, N. Y.
Union Carbide Co. Sault Ste. Marie, Mich.
Union Carbide Co... Welland, Ont.
Union Carbide Co. Norway

Refractory Materials for Furnaces

American Refractories Co. Harper, Ohio
[10]Coplay Portland Cem. Mfg. Co. . Coplay, Pa.
Dolomite Products Co. . Maple Grove, Ohio
[10]Harbison-Walker Refractories Co.......................Chester, Pa.
Northwest Magnesite Co... Chewellah, Wash.

Fertilizer Industry

Phosphate Rock

Armour Fertilizer Works....Bartow, Fla.

Tankage and Garbage

International Agr. Corp.....Lockland, Ohio
International Agr. Corp.....Norfolk, Va.

Potash Extraction

From Sericite[11]
American Potash Co.. .....Portland, Ga.

From Greensand & Marl
Altantic Potash Co.... ....Stockertown, Pa.

From Alunite (with alumina filter-cake as by-product)
Florence Mining & Milling Co. Marysville, Utah
Mineral Products Corp......Marysville, Utah

Materials Rich in Potash

Feldspar Shale (Gneiss) Calcined in rotary dryers for fertilizer filler
American Chem. & Min. Co.. Atlanta, Ga.

Cement Kiln Flue Dust, rich in potash, is recovered by the Cottrell Electrostatic Precipitation Process at the following plants using pulverized coal:
Alpha Portland Cement Co.. Alsen, N. Y.
Security Cement & Lime Co.. Hagerstown, Md.

Miscellaneous Industries

Bauxite Ore (Rotary Dryer)
[1]American Bauxite Co.......Bauxite, Ark.

Chemicals (Rotary Kilns)
Clinchfield Products Corp.... Johnson City, Tenn.

Oil Stills
Standard Oil Co. .... Richmond, Cal.

[1] Denotes installations under construction or just starting up.

[2] Waste heat or direct-firing.

[3] Five American railroads have recently been experimenting with pulverized coal on single locomotives.

[4] Twelve locomotives in operation.

[5] One 9600-ton freight steamship authorized.

[6] Steel bars are heated in these furnaces for rolling into sheets. One of the operations consists in rolling the sheets in pairs.

[7] Copper, zinc, silver, and gold from the same ore, which is treated in a reverberatory furnace.

[8] Cement in 1916, Mineral Resources of the U. S. U. S. Geological Survey.

[9] Small sizes of limestone only.

[10] Magnesite.

[11] Sericite is a variety of mica made up of small elongated silver-colored shreds. It resembles talc.

Congress on National Service

(National Security League)

By G. L. Alexander

Foreign Department, General Electric Company

The National Security League is a nation-wide organization which includes national leaders in statecraft, education, and politics. It was founded in 1914, by Mr. S. Stanwood Menken of New York, to seek and to apply means for promoting the security of our national welfare. The unremitting and successful development of its patriotic activities has led to its becoming recognized by the Government as an official agent for the distribution of Federal propaganda. We recommend that our readers give thoughtful consideration to the following record of the proceedings of the latest national assembly of the League.—Editor.

The National Security League recently completed another* truly memorable congress for national service. Its members and invited guests gathered at Hotel La Salle, Chicago, on Feb. 21, 22, and 23 this year, to formulate plans for educating the American public concerning the problems of the war, and the new responsibilities of citizenship. Among the prominent persons attending, many of them speakers, were the following: ex-President Taft, Governors Lowden (Illinois), Whitman (New York), Harding (Iowa), Cox (Ohio), Manning (South Carolina), Brough (Arkansas), Lindsey (New Mexico), and Burnquist (Minnesota), Charles Edward Russel, Member of the Root Commission to Russia, Bainbridge Colby of the United States Shipping Board, Charles P. Neill, former United States Commissioner of Labor, Samuel Insull, Chairman of the Illinois Council of National Defense, Elihu Root, and Alton B. Parker.

PROMINENT ISSUES DISCUSSED AND ADVOCATED

The necessity for arousing American morale to insure the prosecution of the war on the biggest scale possible.

The necessity for each person in all stations of life doing his and her part.

The necessity for making every person in the country realize that the struggle is a monumental one and will affect everyone's life to some degree. The people must be awakened to the true import of the struggle, and the situation is one which must be faced steadily and bravely.

Adverse and destructive criticism of the administration must cease.

The thought of peace without victory must be absolutely banished.

The need for meting out severe punishment to those found guilty of seditious practices.

The war must be won no matter what its price in blood and treasure.

Universal military training and service must be obligatory.

RESOLUTIONS UNANIMOUSLY PASSED

1. We stand for the continuance of the war until victory is attained. We condemn all efforts toward peace without victory. All discussion of such a peace weakens the power and spirit of the Nation. As Lincoln said to the pacifists of his day, "We accepted this war for a worthy object, and the war will end when that object is attained. Under God we hope it will not end until that time."

2. We firmly believe in the extension of all educational efforts to secure a full understanding of the issues of the war, of the necessity for its vigorous prosecution, and of the obligation for service resting upon every man, woman, and child. We approve the campaign of patriotism through education planned and now being pushed by the National Security League, with the immediate purpose of defeating German propaganda in the United States and of solidifying and strengthening the loyal spirit of the nation to win the war.

3. We re-assert our conviction that without National preparedness for defense there is no safety. Therefore, we favor the early adoption of universal military training as a permanent National policy.

4. We urge the people of this country not to give office to anyone who is not known to be loyally supporting our government in the war.

5. We demand rigorous treatment of enemy agencies, men, literature, and propaganda by the Federal, State, and local authorities, and by the public.

*The proceedings of the League's "Congress on Constructive Patriotism" at the New Willard Hotel, Washington, D. C. Jan. 25, 26, and 27, 1917, is reported in the General Electric Review, April 1917, page 268.

6. We denounce all organizations that attack Constitutional Government, that appeal to the disloyal, that seek class advantage or selfish interest, and that engender strife or division among our people, as hampering the success of our cause, as weakening our power, and as giving aid and comfort to our enemies.

7. We declare that the immediate and supreme duty of the nation and of every citizen is to do all that can be done to win the war. At this time, all other questions and policies are subordinate and should be considered only in their relation to this determined end. We declare that the establishment of the rule of justice and right demands sacrifices, which must be made by every citizen to any extent necessary, even to that of life itself.

PHYSICAL TRAINING

The belief that universal obligatory military training and service is of paramount importance to the youth of the country was expressed by practically all of the speakers and was concurred in by all of the delegates. Ex-President Taft, who at one time was one of the country's greatest pacifists, has been converted to the belief in military training, and will advocate its adoption as a permanent policy of the Government. This remarkable change of front by one of our ex-presidents has been brought about by the alarming rejection of applicants for military service, because of physical defects. The average rejection by army surgeons throughout the country for physical defects is exactly twenty-nine per cent. In some sections of the country it has run as high as fifty per cent.

Walter Camp, probably one of the greatest coachers the country has ever produced, is making a very serious effort to create an interest in physical exercises for those most needing it. Mr. Camp will soon issue a pamphlet showing about a dozen exercises, and outlining a brief course in calisthenics, for the benefit of everyone. Mr. Camp said, "God hates a quitter, and when nature gives out every man is a quitter, for the greatest heart and courage in the world will not help him when nature reaches her limit. Nature never meant a man to be old at thirty, fat at forty, and dependent upon a motor car at fifty."

Mr. Camp recommended that industrial plants organize classes in physical training. He believes the companies would be repaid many times over by the increased quality and quantity of the work done.

Governor Whitman stated that last year New York State conducted the first training camp of its kind ever attempted by any state; that 1700 boys from 350 cities in the state were given a month's training, at the state's expense, with excellent results: and that it is expected that ten times this number will be sent into camp this year. Other states, namely, Illinois, California, Rhode Island, Nevada, New Jersey, and Connecticut, are now enacting similar laws for the upbuilding of the youth of the states.

THE LOYALTY OF AMERICAN UNIVERSITIES

The voluntary response made by American colleges and universities in answering the call of the nation for men has not been surpassed in any country of the world. Thirty-five per cent of the total enrolled undergraduates of the country is a conservative estimate of those who have joined the colors since the declaration of war on Germany. This is a record of which America should be proud.

Dr. Ray Lyman Wilber, President of Leland Stanford University, made a notable address upon this subject. Some extracts from it follow:

"Nations are like individuals, and develop or lose character or morals in much the same way."

"The worst inheritance a man can have is riches without incentive."

"Six months from now we will be a changed nation."

"It must be brought home to all that to stop incentive in the breast of man is to kill manhood."

"Society can meet its labor problems fairly if it faces them squarely."

"We must block the menace of that type of socialism that would blind men to the need of individual effort. It ruins citizens just as surely as the careless, indifferent parent of wealth ruins his sons and daughters."

"The great vital issue after the War will be to maintain the co-operation that has come with it and yet to retain our cherished personal independence."

INTERNATIONAL LAW: ITS SANCTITY

John Bradley Winslow, Chief Justice of the Supreme Court of Wisconsin, presented a study of international law, its observances and violations. Mr. Winslow stated that we are face to face with a nation composed of people who believe themselves to be supermen, clothed with a God-given mission to conquer the world; people led by a ruler who believes himself divinely called to the task just as fully as Mohammed believed it, and with the same weapon—the sword.

If we are to use the world "law" in its broadest sense as including those principles which the judgment of the people has approved, and which have been generally accepted as correct, then the term "international law" is accurately used, even though there is no sanction behind it. Mr. Winslow states that it can be correctly defined as the aggregate of the rules to which nations have agreed to conform in their relations toward one another. It consists of rules of action expressly or tacitly agreed upon by equals, not of commands laid down by a superior; it may be called in a real sense the audible voice of the world's conscience, the measure of that great gulf which separates the savage tribe from the modern state, the cave man from the twentieth century citizen.

CONSERVATION OF LABOR AND FOOD

Six hundred thousand young men have left the farming industries (constituting as it has 31 per cent of the country's total industries) since the declaration of war against Germany, they being attracted by the much larger wages of the factory.

Reports made at the Congress indicated that the Governors of several of the big farming states in the west are awake to the situation and have already taken measures to correct it. Under the direction of their Agricultural Colleges, the respective states will plant less of those goods which produce little fat, and correspondingly more of those which produce considerable fat.

Of all the food products grown, but 12 per cent is used to sustain human life; the remaining 88 per cent is used to sustain animal life. Only those farm products absolutely imperative for the sustenance of life will be grown.

CONCLUDING ADDRESS

Bainbridge Colby of the U. S. Shipping Board, one of the biggest figures in the prosecution of the War, expressed the opinion that the country still lacked a true appreciation of the need for an absolutely united effort, but that we were fast approaching that day when all work would converge on a single objective, and that objective would be attained when the cause as laid down by our President had been realized, and only then.

How to Succeed*

By John L. Bailey
Consolidated Gas Electric Light & Power Co., Baltimore, Md.

There are many attributes going to make up a successful business man or woman. They are honesty, courage, tact, personality, sympathy, co-operation, and observation.

Honesty means being honest in thought, word, and deed. An honest person must first of all be honest with himself; be fair and candid in dealing with others; be upright in business transactions; and be unwilling to commit or countenance fraud.

Courage is next: moral courage, which enables you to meet danger with intrepidity, calmness, and firmness, that quality which enables you to pursue a course deemed right by you although it may incur contempt or disapproval; and physical courage, depending upon physical fitness. Muscular strength alone has little to do with courage. Possess the courage of conviction, the courage to do what *you* know to be right; be a fearless thinker and speaker, for without such courage you may often lose the opportunity to exercise some of *your* particular qualifications. Have the courage to change your views when shown to be wrong.

Tact is the quality of mind which enables us to quickly appreciate and to do the right thing at the right time. Tact is the application of common sense to see that diplomacy is exercised in delicate situations. Tact, in other words, is the mental discernment shown in saying or doing the thing which will avoid complications in one form or another; and we find excellent training for our powers of tact in considering the motives of others, forecasting the consequences of certain actions and being governed accordingly. Don't speak hastily or thoughtlessly, for many a remark so made is attributed to a lack of tact, when, as a matter of fact, it was gross carelessness.

* Abstracted from an address before the members of the Baltimore Consolidated Company, Section of the N. E. L. A.

Personality is that attribute which marks one man different from another: a difference in character, in will, or in being. We all have a manner—an individuality. It may be natural or it may be a cultivated pose, but there need be no one who puts forth an honest effort who cannot provide himself with some of the qualities of good or even an attractive personality. You have heard said many a time, "Mr. So-and-So has such a *pleasing* personality, or such a *strong* personality." How does he do it? Observe his actions and his manner and try to cultivate in yourself the thing that was pleasing and attractive in *his* manner, but do not simply copy—make the new trait a part of yourself.

Sympathy is nothing more than fellow-feeling—being agreeable to one another. We are apt to be too much wrapped up in ourselves—too selfish with our thoughts and lives to pay much heed to the needs of others, but it pays to give consideration to the other fellow—to know what his difficulties are and be governed accordingly.

Co-operation. What is co-operation but a welding together of interests? Usually there is some incentive or motive underlying most schemes requiring co-operation; but for the big success of life there must be individual and collective co-operation—a working together of several or any number of interests for the common good of all.

Observation is the next attribute to be given consideration. The power to observe is not a natural gift, and while this faculty is more highly developed in some than in others, we can safely attribute these qualities to a matter of training. Keep the eyes and ears wide open. Get away from the habit of doing things mechanically for, so soon as you do, work which previously seemed drudgery will immediately become interesting.

Anyone with but ordinary intelligence and training can perform a task which has been designed for him, but it must of necessity be an observant mind which is capable of constructing an effective program of work.

Decide to perform your daily tasks thoroughly and well, every one of them, no matter how trivial they may look to you. Always be "on your mettle." It is a wonderful training which soon becomes a habit. Understand why you are performing the tasks in any certain manner. Can you improve upon the method employed? If so, offer the suggestion for improvement and advance the arguments in its favor. Argue your own case; surely no one should know better than you how the tasks which you daily perform can best be done. And when a new or different line of operation is given you, before you blindly undertake to do it, investigate the various operations to be included in the performance and be sure when you start that you are on the right track. Make haste slowly. A little preliminary study of the matter may often save a great deal of time and even money.

Have you ever stopped to analyze *your* personal program? Are you living in a manner which will keep you physically fit? You owe it to yourself to do this. Take an inventory of yourself. There are many ways in which all of us could make some alterations in our mode of living which would redound to the mutual benefit of ourselves, our employers, and to the community as a whole.

A mind trained to observe and analyze should be fortified by education, and there never was a greater demand for educated men and women than exists at the present time. The evident need for education is manifesting itself more and more every day and in more and more lines of occupation; and every person who has the wisdom and self-interest to see to it that he has the proper educational foundation may rest assured that his rise in the business world will come as a natural course of events, for an educated person cannot be held down unless by express desire; he is a trained man with a trained mind and that training has made him restive to get ahead.

The importance of higher education cannot be exaggerated. This is especially true in view of the changed economic conditions which will prevail during the next decade and which will require a much higher degree of education than formerly or at present. This is well recognized by all educated thinkers, and they have issued the warning—make sure you heed it and be prepared.

Let us not be tempted to set aside educational work "because of the war," which has become a standard reason for everything abnormal; but "because of the war" let us prepare ourselves now and be ready to undertake the greater responsibilities which are bound to come to every one of us.

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THE U.S.S. "PENNSYLVANIA" AND A MERCHANT SHIP ANCHORED IN HAMPTON ROADS

The article "Development of Electric Cast-steel Anchor Chain" in this issue describes a method for speeding up the production of anchor chain to equip our rapidly growing Navy and Merchant Marine

General Electric Review

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE | Editor, JOHN R. HEWETT | Associate Editor, B. M. EOFF | Assistant Editor, E. C. SANDERS

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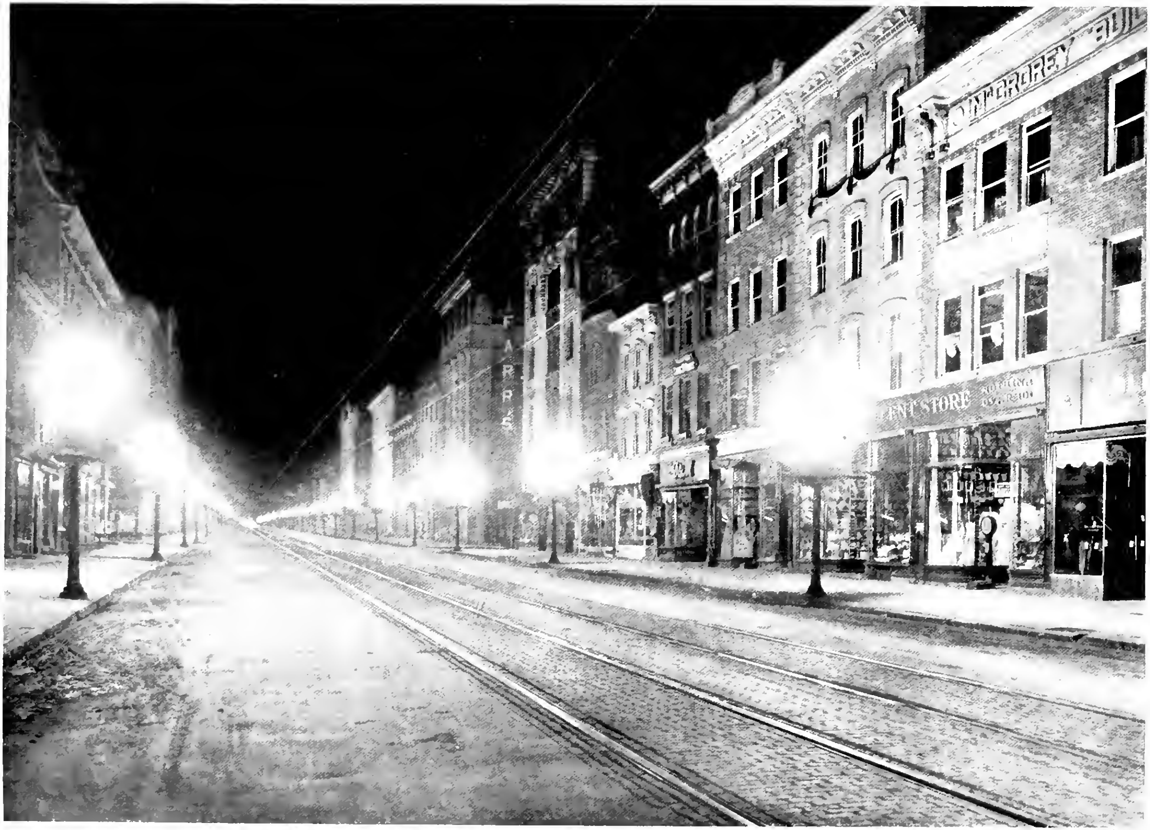

Night view of white-way lighting with ornamental Novalux units in the business district of Allentown, Pa. The upward light from these units is useful in lighting the building fronts. For residential districts and parks, where the upward light would be wasted, a special type of unit has been designed, see page 430.

GENERAL ELECTRIC REVIEW

ILLUMINATION

That the study of light and the possibilities of artificial illumination have engaged the thoughtful attention of men of an investigative turn of mind since the dawn of history is evidenced by the frequent reference to these subjects in the records of antiquity.

Antedating the Christian era by centuries we find evidence of a considerable knowledge of the principles of the reflection and refraction of light, practically applied to a certain limited extent for ordinary illumination, as well as for ceremonial and religious purposes.

With a few notable exceptions this knowledge of the ancients was largely of an empirical nature, and most of the fundamental laws governing the action of light as generally accepted by the illuminating engineer of today were not scientifically defined until comparatively recent times.

By the middle of the nineteenth century the theory of the spectroscope and the laws governing the reflection, refraction, and polarization of light were widely known and became the basis of the phenomenal advances achieved in the field of illumination with the development of the electric arc and incandescent lamps.

From this humble birth, which we may regard as more in the realm of pure science than engineering, has grown what today is recognized as the science and art of illuminating engineering. The engineer engaged in this work, in addition to his knowledge of general engineering and economics, must have at least a working knowledge of optics, psychology, and architecture, for these subjects sometimes play as important a part in the general scheme as do the constructive and performance features.

We find progressive industrial plants eager to adopt the principles of this new science, because their adoption means increased and better production. Many of our states through their industrial commissions have established a code of lighting which makes it mandatory upon industrial establishments to maintain adequate light to safeguard the worker's eyesight and minimize the accident hazard. The federal government has a similar code covering industries engaged in government work. Automobile and locomotive headlights are receiving the attention of the state legislature as matters for state control. Numerous other instances emphasizing the importance of proper lighting to commerce and industry might be cited.

Equally as great advances are found in the co-ordination of light to art and architecture. The so-called floodlighting of our monumental buildings, so that their beauty may be enjoyed at night as well as by day, has become quite commonplace throughout the country. The artistic treatment of municipal lighting standards and the use of color are contributions of the illuminating engineer which have added greatly to the city-beautiful idea of our more progressive cities. We are all conscious of the greater comfort and more pleasing atmosphere associated with modern interior lighting equipment, and we are not likely to question the psychologist when he tells us that the color of light influences our feelings, or with the architect or artist when he says that his efforts may be entirely annulled by improper direction, diffusion, or color of light.

The magnitude of the service rendered by illuminating engineers in the last decade is such that its influence today is felt in practically every activity of man where an adequate substitute for natural light is required. In consequence of the immense amount of detailed work required to secure high efficiency for each particular class of illumination, the illuminating engineer has, in many cases, developed into a specialist devoting most of his time and effort to the accomplishment of improved illumination along certain definite lines, and the results secured have fully justified the creation of this new type of engineer.

The three articles in this issue on the general subject of illumination are indicative of this tendency toward and necessity for specialization in this branch of the Electrical Industry and at the same time illustrate its theoretical and pragmatic value.

Development of Electric Cast-steel Anchor Chain

By W. L. Merrill

Power and Mining Engineering Department, General Electric Company

Rarely has the solution of a war emergency problem been obtained with such promptness and unexpected success as in the development of an economical method for greatly increasing the production of stud-link anchor chain. On September 17, 1917, the Emergency Fleet Corporation appealed to the General Engineering Committee of the Council of National Defense for assistance in anchor chain production by development of improved methods. On October 26, 1917, a cast-steel chain had been developed which was considerably superior to the old wrought-iron chain in practically all vital respects. On May 1st an order of approximately one million dollars' worth of cast-steel anchor chain was placed by the Emergency Fleet Corporation, on which the net saving to the Government was about $50,000. If the war lasts two years longer, the total saving will probably exceed a million dollars, for the price will come down as the methods of manufacture are developed.—Editor.

At the time our large shipping program was decided upon, it was obvious that the United States was in no position to furnish many of the items entering into the construction of ships. One item was anchor chain. The average size merchant ship requires in the neighborhood of 30 tons of anchor chain; and for a program of 1500 ships this item alone would run to approximately 45,000 tons of chain or over five 8000-ton shiploads of chain. To this equipment had to be added the complement of anchors and wild cats together with the necessary storage facilities. This in itself was no small part of the ship program.

The anchor chain industry has for the most part been limited to foreign manufacture as the amount of merchant marine built in recent years in this country has been practically negligible. Our navy, however, manufactured most of its chain at the Charleston Navy Yard; but as the time for building a battleship varies from three to five years, it is obvious that the anchor chain could readily be produced during the interval between the time the keel is laid and the time the chain is required, since comparatively few ships have been under construction at the same time.

The universal method of making chain, with one or two exceptions, has been by hand forging; and a gang of chain makers could produce but a few links each day. It therefore seemed inevitable that a new process for making anchor chain must be developed or a great army of workmen would have to be trained and facilities supplied for producing chain by the original methods.

To solve this dilemma, the Shipping Board appealed to the Engineering Committee of the Council of National Defense to investigate and advise the most economical method of producing anchor chain in large quantities. Accordingly, a sub-committee was appointed consisting of representatives of Chain Manufacturers, Navy Department, Classification Societies, U. S. Steamboat Inspection Service, and the Emergency Fleet Corporation, with the writer as chairman.

From the standpoint of an electrical engineer the problem seemed simple, as

Fig. 1. Electric 16-ft. Elevator Dredge Equipped with Chain made up of Links 36 in. long, Wire Diameter 7½ in.

evidently the principal duty of an anchor chain was to connect an anchor at the bottom of the ocean with the bow of a ship and to have sufficient strength to keep the two in fairly close proximity to each other during storms and shore leaves of the crew when in friendly ports. However, the factor of strength did not prove to be of primary importance when considered from the nautical viewpoint. The weight of chain per fathom for a given size ship was the important requirement, and this is obvious when the action of the chain with the ship riding at anchor in a heavy seaway is considered. Assume, for instance, that it is possible to have a thin wire of a strength equal to that of the anchor chain for a certain ship; it is evident that when the ship heads into the wind with the bow in the trough of the sea the next wave coming will raise the ship, which action will result in the wire breaking or dragging the anchor. Therefore, it is evident that weight per fathom of chain is a very important factor, and investigation has shown that chain of sufficient weight for a given ship will, if properly made of a good material, have sufficient strength.

One of the first investigations carried on by the Committee was to consider the substitution of electric welding for hand welding of chain. This was successfully done; however, as in the hand process of welding and in the machine forging process, as used at the Charleston Navy Yard, it simply speeded up but one of a number of operations necessary to produce the chain.

It was then decided that, whatever be the process of welding the chain, at least every other link could be drop-forged to shape, including the stud, and the alternate link

Fig. 2. Close-up View showing Several of the Links Referred to in Fig. 1

could be welded by hand, machine, or electrically. A set of dies for 2-inch chain was accordingly made at the Schenectady Works of the General Electric Company, and a number of links were forged. Tests showed them to be successful. It was thought that the Fleet Corporation would be able to obtain drop hammers in various parts of the country, order links forged from cast ingots, and have the links shipped to chain shops where they could be welded in the finished chain, thereby materially reducing the labor on half of the production. This method would not particularly adapt itself to the heavier chains as it is much easier for a chain maker to weld a link at the end of a chain than to connect two pieces of chain together; and, while it would have undoubtedly speeded up the production of chain, on the whole it would have handicapped that part of the process in which hand welding would be employed.

From the foregoing it appeared that any process for making chain, which would make a real reduction in the over-all labor, must be some radical change from the conventional methods, particularly eliminating the preparation of the material for the chain, the hand method requiring:

Starting with pig iron
- Melting down
- Puddling
- Squeezing
- Rolling ingots into bars
- Cutting bars
- Bending links
- Scarfing for the welds
- Welding
- Inserting stud.

For each operation in bringing the link to shape, repeated heating is necessary. It appeared that to turn out the amount of chain required by the Shipping Board in the time estimated, the hand method would have required more man-hours and weight of equipment to produce the furnaces, machinery, etc., than it would to produce the chain itself.

In 1911 the Marion Steam Shovel Co. had occasion to build some chain for dredge work, the links being 36 inches long, and the wire $7\frac{1}{2}$ inches in diameter, Figs. 1 and 2. This was made by casting one link at a time with the molds interlocked. This chain was entirely successful and is in service today. It occurred to the writer that it might be possible to cast much smaller chain than this by the use of electric steel. Accordingly, samples were made in the Schenectady Works which proved that successful chain could be made by this process. The first attempt was made by die-casting the links in the form shown in Fig. 3. The studs were afterwards placed in position, the same as in hand welded chain, Fig. 5. It was found, however, that while it was possible to make die-cast chain from electric steel, it was not feasible for a large production since there is a very critical time at which the molds should be opened to prevent shrinkage cracks; and if opened too soon, the metal of course would not be congealed. Therefore, dry sand molds were resorted to and successful chain was made by this method.

The Classification Societies' requirements for 2-inch chain are as follows:

Breaking test	225792 lb.
Proof test	161280 lb.

There are no requirements for elongation or reduction in area. Our first samples tested at the Bureau of Standards were nearly double the strength of wrought chain, and it was felt by some members of the Committee that this was the solution of the chain problem. Other members felt that further tests would be necessary before adopting cast-steel chain, and seemed to be much exercised about the comparative corrodible quality of electric steel and wrought iron. But, there being no thus causing failure. Consequently, comparative tests were made by subjecting single links to a blow under a drop hammer, which somewhat approximates the action of the abnormal conditions.

It will be noted from the links subjected to this test, Fig. 6, that neither the electric steel nor the wrought iron showed failure; also, that the electric steel links showed less deformation than the wrought. The Classification Societies, however, did not feel like

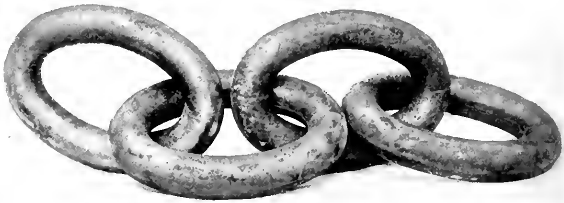

Fig. 3. First Anchor-chain Links Electric Die-cast at the Schenectady Works

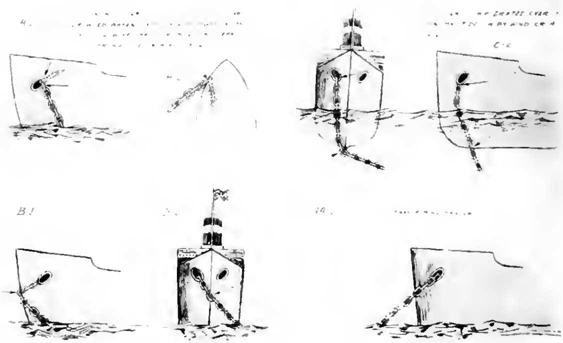

Fig. 4. Diagrams showing Abnormal Conditions Under which Anchor Chain May Fail and also showing the Easy Riding Hawser Condition

reliable data available on wrought chain, it was felt that the life of electric steel chain in comparison would at least last during the present emergency, and therefore the question of corrosion was dismissed.

From data collected from the Navy Department and various other sources, it was evident that practically all the anchor chain failures were due to accident and not to normal conditions. Fig. 4 shows the abnormal conditions to which chain may be subjected.

approving cast-steel chain even with this evidence. Further investigation was therefore carried on.

It was decided at this time to extend the activities of this investigation and methods of casting. Consequently, the National Malleable Castings Co. was interested in making sample electric steel chain. The E. H. Mumford Co. was asked to investigate automatic machinery for producing molds. These companies worked up processes for

Fig. 5. The Section of Chain shown in Fig. 3 after the Studs have been Placed in Position

Fig. 6. Wrought-iron and Electric Cast-steel Links which Have Been Subjected to an Impact Test Under a Drop Hammer

No. 13. Wrought iron. One stroke of hammer caused the deformation shown. No fractures. Stud remained in place

No. 4. Wrought iron. Received two strokes of hammer. No fracture. Link opened sufficiently for stud to drop out.

No. 30. Electric cast steel. Received two strokes of hammer. No fracture. Link opened sufficiently for stud to fall out

No. 31. Electric cast steel. One stroke of hammer caused deformation shown. No fracture. Stud remained in place

Fig. 7. 3[illegible]-in. Naco Anchor-chain Links in a Static Testing Machine, National Malleable Castings Co

Fig. 8. 2[illegible]-in. Naco Anchor-chain Links in a Standard MCB Drop Testing Machine. National Malleable Castings Co

molding chain in sections complete with the studs cast as a part of the link, and successful chain was made by this process in several foundries. The National Malleable Castings Co. then made chain in various sizes from $1^3/_8$ in. to $2^7/_8$ in., the $1^3/_8$-in. link apparently being the smallest that it is at present practicable to mold. Tests were then carried on at their plant with various samples of chain which they had cast, in comparison with hand-wrought chain and Navy chain from the Charleston Navy Yard. These tests consisted of tensile tests and shock tests in a standard MCB machine.

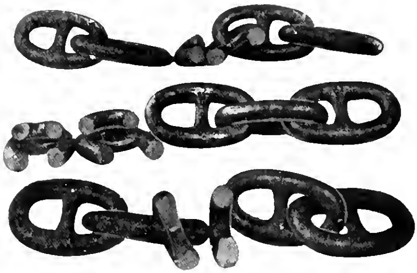

Fig. 9. Results of Static Tests on $2^1/_4$-in. Naco Electric Steel Links

Fig. 10. Two-inch Electric Cast-steel Links Made at Schenectady and Tested at the Charleston Navy Yard

Fig. 7 shows the pulling tests of a $2^7/_8$-in. triplet in a static machine of 1,000,000-lb. capacity.

Fig. 8 shows five links suspended in the standard MCB drop test machine. In all cases the electric steel chain showed greater tensile strength and stood more punishment in the drop test than the wrought chain.

Further tests were made at the National Malleable Casting Company's plant to get comparative data and specifications on a shock bending test, somewhat similar to Fig. 6.

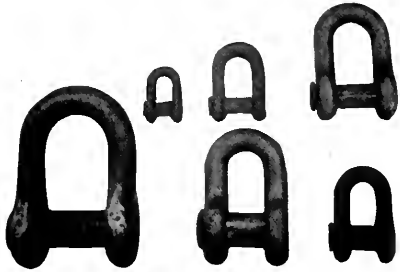

Fig. 11. Standard Shackles of Naco Electric Cast Steel

As a result of this work, the American Bureau of Shipping, American Lloyds, and English Lloyds have approved and issued specifications permitting the use of electric steel anchor chain on shipboard, these specifications differing in the main from those for wrought chain in the following points.

The original breaking test of wrought chain is now specified for the proof test with proportional increase in tests for sample links above this of 40 per cent. For example, the original proof tests of 2-inch chain, 161,280 lb.; for electric steel, 225,972 lb. The original breaking test for wrought chain, 225,792 lb.; for cast steel, 316,109 lb. To this is added a shock bending test for sample links as mentioned above.

When we consider the method of making anchor chain a year ago and follow the ore from the mine to the finished product and compare it with the electric steel method, we must realize that: first, better chain can be produced; second, tremendous economy can be secured in the conservation of man-hours, machinery, fuel, and transportation, since the conservative estimate of a foundry equipped with an open hearth for melting down and a 10-ton electric furnace for refining should produce 70 tons of finished chain each 24 hours, based on a two-inch average size. Practically no skilled labor is required, outside of that for supervision.

Losses and Trouble Caused by Impure Boiler Feed Water

SPECIAL REFERENCE TO FLOW METERS

By H. H. Mapelsden

Flow Meter Engineering Department, General Electric Company

The United States coal production during 1917 was fifty million tons greater than that in 1916, yet the total was fifty million tons short of the requirements of industry. This shortage and the overloaded condition of the railroads temporarily enforced a partial or entire shut-down of many industrial activities last winter. Obviously, we must display more intelligence in utilizing our fuel resources; we must become more active in conserving our coal supply, which means that only the minimum necessary amount of coal is to be burned and waste is to be eliminated insofar as possible. The intelligent management of boiler plants and the prevention of fuel waste can be greatly assisted by the use of steam and water flow meters. Bad feed water has caused trouble when nozzle plugs are used with these meters and consequently there has been developed a special flow nozzle which can be satisfactorily used under these conditions.—Editor.

Material Suspended in Water

In many plants throughout the country, especially in the middle west, dirty river feed water causes serious incrustation and deposits in boilers and piping. The accompanying wear of valves, pump cylinders, and pistons necessitates a considerable annual expenditure for repairs. Steam engine cylinders, turbine buckets, and nozzles are likewise subjected to wear.

In some plants this trouble has been decreased or eliminated by settling basins, in which the suspended matter is partly or wholly removed by gravitation. Without doubt, the cost of such settling basins is prohibitive for many plants. In such cases, frequent boiler cleaning is necessary to maintain reasonable evaporation by the boiler. Nevertheless, the waste of fuel will gradually increase between periods of boiler cleaning, and the repair expense on pumps, valves, and engines cannot be eliminated.

Material in Solution in Water

A much more prevalent cause of trouble is the presence of scale-forming compounds, such as the carbonates and sulphates of both lime and magnesia, iron oxide, and other mineral combinations and organic matter. These are in solution and are thrown down in the boiler, making frequent cleaning of the boiler tubes vital to economical operation.

To be able to withdraw boilers from service, for the purpose of cleaning, spare boilers are necessary and some of these are idle practically all of the time. The expense of cleaning is a considerable factor, and also the tubes deteriorate more rapidly than when chemically pure water is used.

In plants where the main units are run condensing, the condensed steam is usually returned to the boilers. It is then necessary to supply only a small amount of fresh water to make up the leakage. This make-up water should preferably be distilled water, for even a small amount of scale-forming material eventually results in a decrease in operating efficiency.

Numerous chemical compounds are used to prevent the pitting of boiler tubes and the formation of scale. These range from substances claimed to be cures for all cases to specific treatments dependent upon analysis of the impurities in each particular case. The use of the so-called universal "boiler dope" aggravates the trouble in some cases and causes foaming in others. This latter may lead to disastrous water hammer. Scientific treatment will in many cases eliminate the foregoing troubles.

The operation of G-E Flow Meters when connected to the standard nozzle plugs is directly affected by dirt or by scale-forming materials in the water or by some compounds introduced to prevent scale. (See Fig. 1.) The small passages or openings in the nozzle plugs become partially or wholly stopped up. Frequent blowing out will prevent this stoppage, but sometimes this attention is not given the meter. The meter then responds sluggishly or not at all to changes in flow. The fault is of course entirely outside of the meter, but it is sometimes discredited and even removed. As a matter of fact, the meter should be credited with detecting poor conditions, the remedy of which would be beneficial to the plant.

The flow nozzle shown in Fig. 2 has been developed primarily for use with flow meters measuring water or steam carrying dirt or other impurities. It has a specially curved approach and a short cylindrical portion

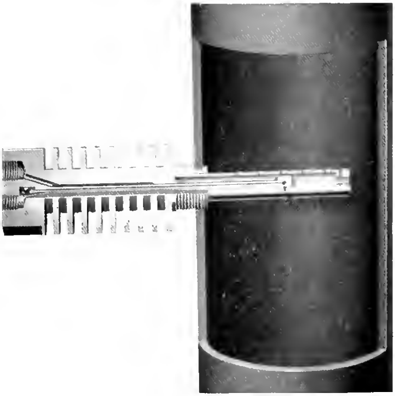

Fig. 1. Sectional View of Nozzle Plug Installed in Pipe

The high-pressure side of the flow meter is connected to the main one and one-quarter pipe diameters before the flow nozzle, and the low-pressure side is connected to the main under the cylindrical portion. (See diagram of arrangement in Fig. 3.) Large connecting pipes are employed, minimizing the possibility of stoppage. Flow nozzles may be installed in horizontal, vertical, or inclined pipes in the various locations shown in Fig. 4.

The pressure loss caused by a flow nozzle is very small. It never exceeds one pound even when the flow meter is provided with the largest internal mechanism in order to measure the highest flows for which it is designed. (See Fig. 5.) In case of low pressures, where the smallest pressure loss is imperative, flow nozzles with large throats are used in conjunction with small internal mechanisms in the meter.

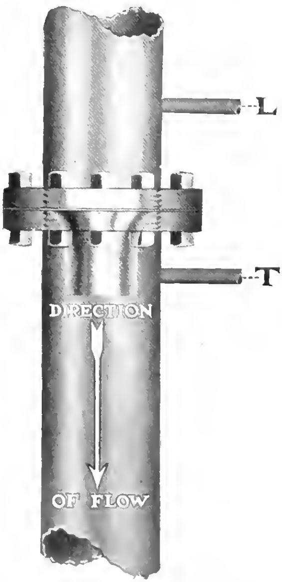

Fig. 2. Phantom View of Flow Nozzle Designed Primarily for Use with Flow Meters Measuring Dirty or Impure Water or Steam

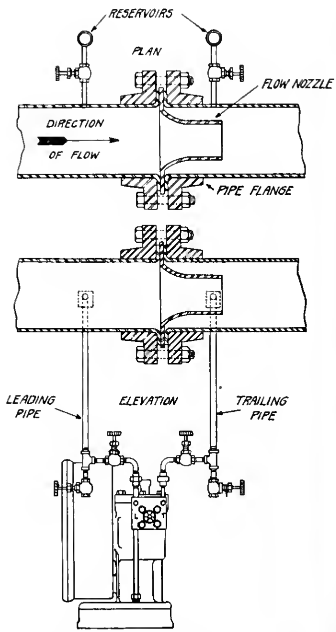

Fig. 3. Arrangement Diagram Showing the Method of Connecting the Flow Meter to the Flow Nozzle shown in Fig. 2

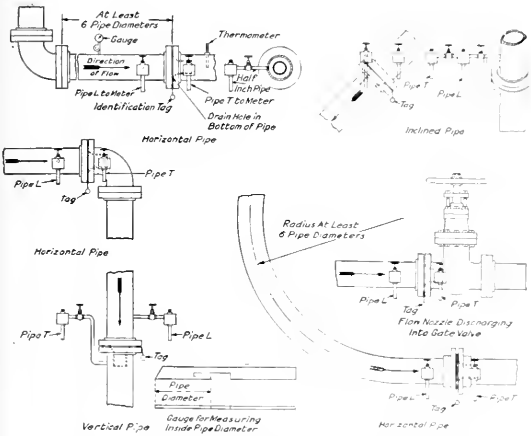

Fig. 4. Diagram Showing Satisfactory Methods of Installing Flow Nozzles under Different Conditions

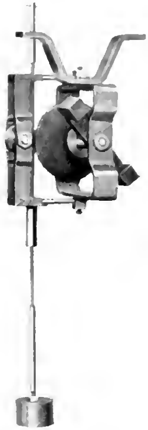

Fig. 5. Internal Mechanism for G-E Flow Meters

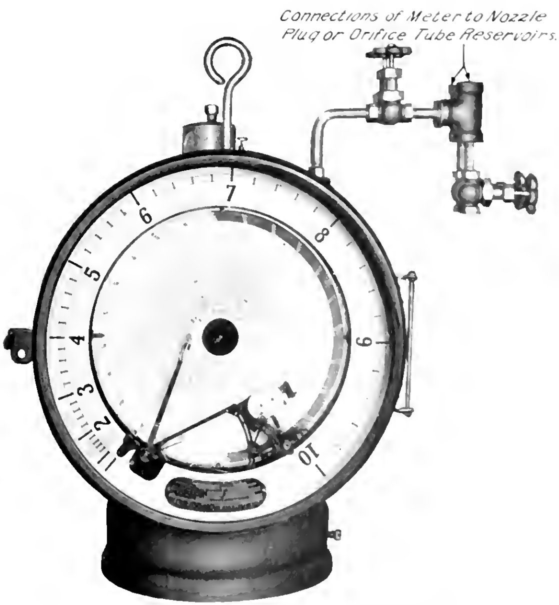

Fig. 6. Indicating Recording Integrating Flow Meter

Temperature Indicator for Transformer Winding

By V. M. Montsinger and A. T. Childs

Transformer Engineering Department, General Electric Company

The present method of rating transformers, based on maximum continuous output, emphasizes the importance of measuring the temperature of transformer windings under actual service conditions. The authors of this article briefly discuss several proposed schemes of accomplishing this measurement and the possible benefits derived by the use of a satisfactory temperature indicator. Finally, they give a detailed description of a recently developed temperature indicator which gives the temperature of transformer windings during service conditions.—Editor.

Until it became the practice to operate transformers continuously at their maximum capacity, it was not usually important to know the internal temperature of the windings during operation. The observation of the maximum oil temperature was generally sufficient, because whenever the temperature of the windings approached the danger point it was only for a short interval. For instance, until within the last two or three years it was the practice to operate apparatus transformers for the greater part of the time with a 40 deg. C. rise, although during short-time overload periods a temperature rise of either 55 or 60 deg. C. was allowed, the 55 deg. rise applying to all transformers excepting those for railway work. This method of rating railway transformers, however, is still used and recognized by the A.I.E.E. although no limit in temperature rise is specified for the nominal rating.

With the present method of rating transformers, namely, to operate continuously with a 55 deg. C. rise, it is important to know the temperature of the windings during operation, because a few degrees variation from the allowable rise will have a marked effect on the life of the transformer. It is evident that the determination of the internal temperature not only protects against overheating but, under certain conditions, may permit greater output with safety. This is true not only for short-time overloads but also for constant conditions when the ambient temperature is below that specified in the A.I.E.E. Standardization Rules.* For example, an increase of approximately one per cent in the kilovolt-amperes capacity of self-cooled transformers can usually be obtained for each degree that the ambient temperature is below 40 deg. C., without exceeding the normal hot-spot limit. The same approximate rate of increase in capacity applies to water-cooled transformers for each degree that the temperature of the ingoing water is below 25 deg. C. Due, however, to variations in the design characteristics of transformers, such as the ratio of iron loss to copper loss, or the ratio of maximum to average temperature, it is unsafe to take advantage of the cooler ambient temperature unless there is a dependable means for determining the maximum temperature of the windings.

On the other hand if it is desirable to conserve the cooling water, this can be accomplished with safety. For example, if the temperature of the ingoing water is 15 deg. C., the amount of water can usually be reduced, without exceeding a safe hot-spot temperature, to one-half the amount that would be required if the temperature were 25 deg. C.

To sum up: the following are the most important advantages in knowing the internal temperature of a transformer during operation.

(1) The insurance against damage from overheating. This should prolong the life of the transformer.

(2) The ability to increase the output or capacity of the transformer.

(a) When the ambient temperature is below normal.

(b) When short-time overloads are required.

(c) When the difference between the hot-spot and the average temperature is negligible.

(3) The possibility of conserving the cooling water for water-cooled transformers.

(a) When the temperature of the ingoing water is below 25 deg. C.

(b) When the load is below normal.

*It should be noted that to exceed the guaranteed rise, whatever be the ambient temperature, is contrary to the present A.I.E.E. Rules (paragraphs 305-A and 386). However, when this rule was adopted, there was no available means for observing temperatures other than that of the top oil. As there are generally no other features besides the maximum temperature which limit the kilovolt-amperes capacity of transformers and as long as the maximum temperature limit is not exceeded even if the guaranteed rise is exceeded, the intent of the Rules will not be violated.

A number of schemes have been proposed for observing the hot-spot temperature of transformers. Very few, however, are suitable for practical application. The reason why they are not suitable is that the construction and potential of transformer windings are usually such that it prevents the placing of a thermometer, thermo-couple, or resistance unit close enough to the winding to determine the temperature of the copper without subjecting the operator to the danger of these potentials. On the other hand, if a resistance unit be sufficiently insulated from the transformer windings, the difference in temperature between it and the windings would be so great that the indicated temperature would not be very reliable. If the internal temperature of the transformer windings is to be accurately observed with safety, it is absolutely necessary that the resistance unit be imbedded in the windings and at the same time insulated from the temperature-indicating instrument. This prevents the use of direct current for energizing the resistance unit.* Alternating current, therefore, must be used.

The first method usually proposed is to place a non-inductive resistance unit between turns of the transformer windings and to force a current through it from the secondary winding of an insulating transformer, whose primary winding is excited from any source of constant potential. The current will change as the resistance (or temperature) of the unit changes. An ammeter in the circuit could be calibrated to read directly in degrees. Due to the fact that a small change in the impressed voltage is equivalent to a fairly large change in the temperature of the resistance unit, the scheme requires perfect voltage regulation which may be prohibitively expensive.

Another proposed scheme is to create, outside the transformer windings, an artificial hot-spot which shall have the same temperature as the actual hot-spot. The artificial hot-spot is heated with current from the secondary winding of a current transformer whose primary winding is connected in series with the load current. The temperature of the artificial hot-spot is therefore a function of the load current. This artificial hot-spot, being insulated from the main transformer windings, allows a thermo-couple or resistance unit to be imbedded in it without subjecting the observer to the danger of high potential.

The successful operation of the foregoing scheme necessitates that two conditions be fulfilled: First, the artificial hot-spot must be designed to be the same as that of the transformer under constant conditions; Second, the artificial hot-spot must duplicate the actual hot-spot temperature for all rapid variations in load.

While the first condition can be approximated fairly closely, it is practically impossible to meet the second condition at the same time. The reason for this is as follows: on the one hand, the internal temperature of a body immersed in oil is, for constant conditions, dependent upon three factors, namely, the temperature of the cooling medium (oil), the surface loss density, and to some extent the mass of the body; while on the other hand, the internal temperature of a body, under varying conditions, is largely dependent upon the thermal capacity of the mass. Furthermore, if at some time during the life of the transformer its temperature rise for a given load should change due to any one of many possible causes, the artificial hot-spot must also change correspondingly. This is rather improbable. The artificial duplication of the internal temperature of a transformer winding under all conditions is obviously difficult if not impossible.

There are other schemes† which have been proposed, but the preceding seem to be the most common.

The primary requisites for the successful operation of any temperature-indicating instrument are three-fold:

(1) The instrument must be safe.

(2) It should be simple in operation.

(3) It must indicate continuously, correctly, and permanently the maximum internal temperature of the windings.

It was with a full appreciation of these requirements that the General Electric Company undertook to develop a suitable temperature indicator for transformers. The result has been the completion of an equipment that meets all the requirements. It is suitable for any type of winding operating at any voltage up to approximately 27,000

*Transformer windings are more open and the voltages are generally higher than in generators where a direct-current type of temperature indicator has been used successfully for the past two or three years. For a description of the direct-current temperature indicator refer to the G. E. REVIEW, May 1917, p. 380.

†It is sometimes asked why a thermometer immersed in the oil cannot be calibrated to show the maximum temperature of the windings. There are two reasons why this cannot be done: first, on account of the lag in temperature; and second, because the difference between the oil and the winding temperatures varies with the load.

volts. This voltage limit can no doubt be increased as more experience is gained in the operation of the instrument under service conditions.

Description of Temperature-indicator Equipment

The scheme referred to in the preceding paragraph employs what is essentially a four-arm bridge. Two arms of the bridge, Fig. 1, are formed by the secondary winding of a potential transformer; the third arm by a constant resistance ***R'***; and the fourth arm by the primary winding of a transformer whose secondary winding is connected to a non-inductive copper resistance ***R*** which is imbedded in the winding of the transformer whose temperature is to be measured.

An alternating electromotive force ***E*** is applied to the primary winding of the potential transformer; and a second electromotive force ***E'*** is induced between the points ***a*** and ***b***. Between these two points are three circuits, two of which, ***acb*** and ***adb***, form the bridge, and the third ***ab*** is the fixed coil circuit of a separately excited dynamometer, ***D***. As the temperature of the transformer changes, the resistance of the copper unit changes, thereby affecting the balance of the bridge. The dynamometer, with its movable coil connected across the points

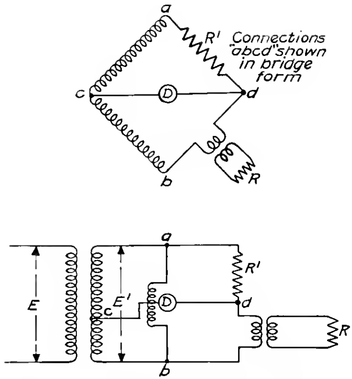

Fig. 1. Simplified Connections of Alternating-current Temperature Indicator

d c, denotes in degrees Centigrade, the amount that the bridge is out of balance.

Although the same fundamental circuits as described are used in the completed form of the temperature indicator, it has been found necessary to add certain features for protection and convenience in switching, etc. A complete wiring diagram is shown in Fig.

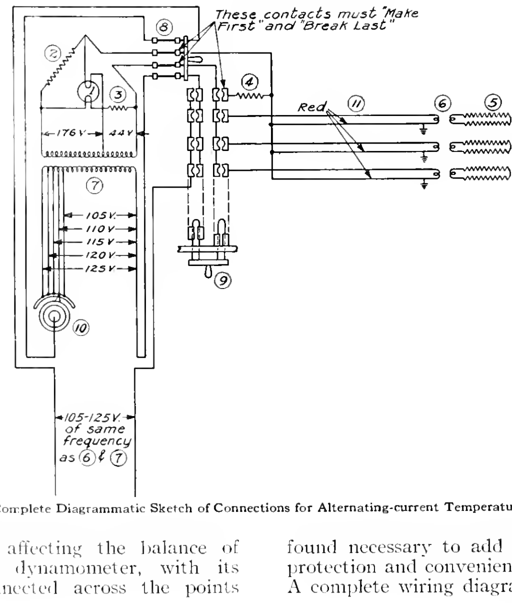

Fig. 2. Complete Diagrammatic Sketch of Connections for Alternating-current Temperature Indicator

2. The various parts shown in this diagram are described briefly as follows:

The indicating instrument *1* is a horizontal edgewise instrument having its scale graduated in two-degree divisions from 20 to 140 deg. C. Its external appearance, Fig. 3, is the same as other meters of this type.

Parts *2, 3,* and *4* are fixed resistances located in perforated cases. These are generally mounted on the back of the switchboard as shown in Fig. 4. Part *4* is used simply to determine whether the meter is working properly. If the plug switch *9* is placed in the first set of receptacles, the checking resistance is substituted for the transformer *6* and its accompanying copper resistance unit *5*. The resistance of *4* is of such a value as to cause an indication of 80 deg. C. providing the indicator is working correctly.

The copper resistance unit *5* consists of two insulated copper wires wound spirally about a flat insulated copper core and joined together at one end of the unit, which makes it non-inductive. The unit is from 20 to 25 feet in length and is placed either between the turns or the strands of the coil, depending on whether one or more than one strand per turn is used.

To prevent the resistance unit forming a floating conductor (electrically speaking) in the transformer, one point of the unit is solidly connected to the adjacent conductor of the main coil. The potential of the unit being the same as that of the adjacent conductor, it is necessary to use only a light insulation; and since it is placed between two equi-temperature conductors, it assumes the temperature of these conductors.

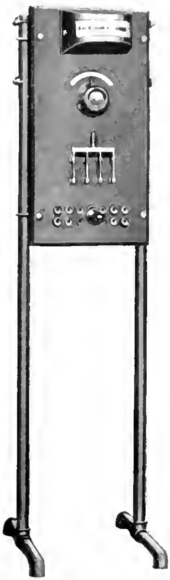

Fig. 3. Front View of Alternating-current Temperature Indicator Panel

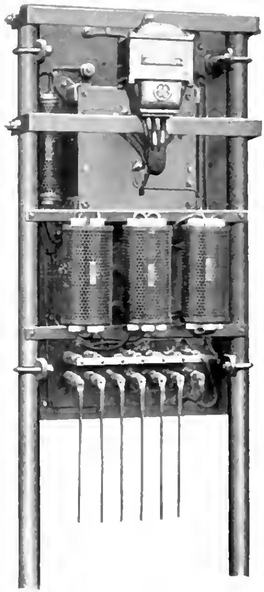

Fig. 4. Back View of Panel shown in Fig. 3

Fig. 5 shows the resistance unit imbedded between the strands of a disk coil of six strands per turn. By placing the main part of the unit near the middle of a coil located at the top of the stack, with coils operating in a horizontal position, approximately the maximum temperature is obtained. The area covered by the bracing insulation (spacing strips) is, of course, operating at a higher temperature than that portion of the coil exposed to the cooling oil. This is especially true if the bracing insulation runs parallel with the conductors, in which case the heat generated under the spacers, in order to escape, must flow across several conductors and their intervening insulation. But with narrow bracings at right angles to the conductors, as used with coils of the circular-coil type construction, it would be expected, and in fact tests show, that the difference in temperature is small—generally not more than 1 or 2 deg. C Also, by

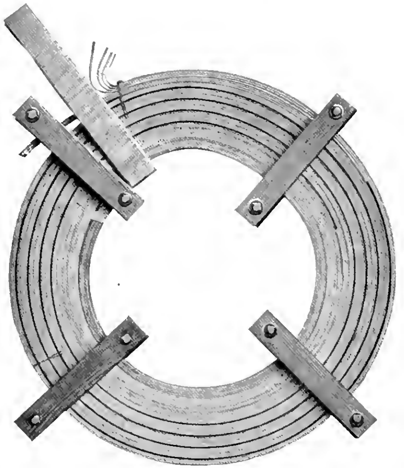

Fig. 5. Disk Coil Wound with Resistance Unit (Four darker turns)

placing the unit near the top of a cylindrical winding, practically the maximum temperature will be obtained; but for windings operating in a vertical position with vertical turns and with a resistance unit of this length, the average temperature is obtained.

It is proper to point out that by giving special attention to the transformer design heating constants, it should not be necessary to place a resistance unit in both the high-voltage and low-voltage windings. There seems to be a general impression that the high-voltage windings run warmer than the low-voltage windings. This is by no means the case. The designer can vary at will the relative temperature of the windings, and consequently can make the condition such that the temperature of the high-voltage winding will not exceed that of the low-voltage winding. One resistance unit placed in the low-voltage windings of each phase should therefore be sufficient.

Part ***6*** is a special transformer used for insulating the resistance unit from the indicating meter. This transformer is mounted under the oil of the main transformer. One of the leads from this insulating transformer to the panel is dead grounded inside the transformer tank, so that the operator is always protected. Since so much depends on this insulating transformer, it receives a higher potential test, before being installed, than is given the main transformer winding in which it is placed. Figs. 6 and 7 show it installed on two different sizes of transformers before being tanked.

Part ***7*** of Fig. 2 is a standard type of potential transformer used for exciting the bridge. It has been mentioned before that, in order for any scheme to prove successful, the temperature meter must not be affected by changes in the exciting voltage, especially around the temperature danger point. Obviously the reading of the meter used in this scheme will change with a change in the exciting voltage, except when the bridge is balanced. The conditions are made such that it will balance at the most important temperature (approximately 100 deg. C.). As the temperature varies from 100 deg. C., the error due to changes in voltage increases. To correct for this, the primary side of the potential transformer is provided with several 5-volt taps which, by means of the dial switch ***10***, permits the operator to adjust the secondary voltage to within about 2.5 per cent of its designed value. If this adjustment is made, the errors due to a voltage change at any temperature are small; and at a temperature in the neighborhood of the balancing point of the bridge, these errors are negligible even for a large variation in the voltage.

A four-pole, single-throw switch ***8*** is provided for interrupting all circuits leading to the panel. The two inside clips are extended so that the impressed voltage will be disconnected before the variable arm of the bridge is broken. If this were not done, a violent deflection of the meter pointer would take place.

The transfer plug switch ***9*** is used for transferring the meter from one transformer to another. This is also arranged so that the excitation is disconnected first. The panel can be provided with a number of receptacles, so that the same equipment may be used for a number of transformers.

The leads ***11*** from the transformer bank to the panel are twin-conductor cable; flame-proof finish for indoor use and lead-covered for outdoor use. They may be any length, providing their resistance does not exceed approximately 1.25 ohms. It is very interesting to note that the insulating transformer affords a means for multiplying the resistance of the copper unit, which allows its equivalent resistance to be made large compared with the resistance of the leads in this arm of the bridge. This permits of a considerable variation in the resistance of the leads without seriously affecting the accuracy of the meter. For example, a change in the temperature of the leads from −40 deg. C. to +40 deg. C., which corresponds to a change in resistance of approximately 40 per cent, causes an error of only about 0.2 deg. C.

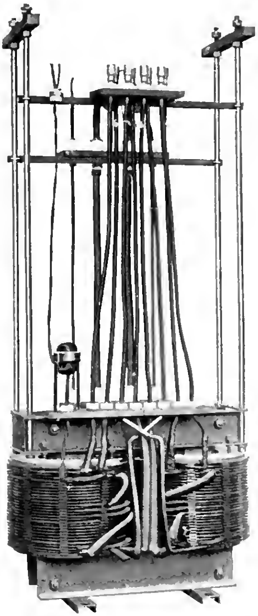

Fig. 6. Core-type 60-cycle, 750 kv-a., 24,000 2400-volt Transformer Showing Method of Bringing out Leads from Resistance Unit Embedded in Low-voltage Coil (Third from top)

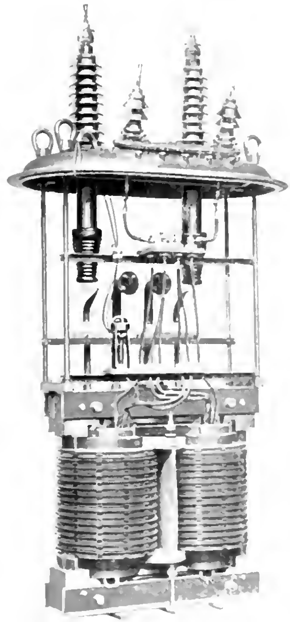

Fig. 7. 60-cycle, 1350 kv-a., 36,000 62,400 Y 2400-volt Cylindrical-disk Type Transformer Showing Method of Bringing Out Leads from Resistance Unit Embedded in Low-voltage Coil

Conclusions

As stated before, the requirements for any temperature-indicating meter are that it must be safe, simple, and permanent. All tests of the equipment made at the factory indicate that these requisites have been met and that the device is a successfully operating instrument for determining the internal temperature of transformer windings.

An Address to Graduating Student Engineers*

By E. W. Rice, Jr.

President of the American Institute of Electrical Engineers; President of the General Electric Company

In this address Mr. Rice refers to the vital importance of the engineer to our social and business structure in peace times, and his indispensability in modern war. The field of engineering has now become so extremely broad that it is impossible to keep posted on even a portion of the developments, and hence specialization is becoming more and more a necessity. Specialization furthers progress, but is apt to lead to a narrowed view, not only of our profession but of our whole outlook on life. This natural result of specialization should be counteracted by devoting some time to a study and appreciation of business, art, politics, etc. In a democracy where the opinions of the mass control the system of government, it is wholly desirable that the influence of the engineer should be felt because of his intimate relationship to our everyday life. To exert this influence intelligently will require a careful study of the social and political affairs of the times.—Editor.

There never was a time when the world had greater need of engineers and of trained technical men. Your country needs you in the war zone; and it also needs you at home. Our country, therefore, is fortunate in the addition to its ranks of trained workers which is being realized at this Commencement season.

Workers as well as fighters are needed, and the work and the fight must both be guided by brains if we are to win this war; and the trained brain should be the best brain for both tasks. I say this to console you for waiting, as I am sure you have, with much impatience, to do your bit in this great struggle; and I am sure that you will not regret the time that you have taken to gain training in your profession. "To do your bit" you must also "do your best" and that you are now well qualified to do.

Engineering is not only the foundation of modern society and institutions but it permeates the whole structure, even as the universal ether permeates matter. Anyone who doubts this has only to consider what would happen in this country if the work of the engineer should suddenly cease.

Our system of transportation, railroads, trolley lines, steamboats, subways, automobiles, transmission of intelligence by telegraph and telephone, wagon roads, bridges, tunnels, city streets, buildings, workshops, mines, and every luxury and every necessity are all dependent upon the work of the scientist and engineer, not only for their creation but for their continuous and successful existence.

Our present complex system of living might go along for a short time, propelled by its own momentum, but it soon would stumble into chaos and decay, destroyed by its own complexity, if it were not constantly guided and maintained by the skilled hand and brains of our trained and educated engineers.

* Delivered before the Graduating Class of Rensselaer Polytechnic Institute, Troy, N. Y., on May 1, 1918.

Such is the dependence of society upon engineering in times of peace and under normal conditions. In war—modern war—the engineer is of even more importance. The men in the trenches must have guns, grenades, gas-masks; trenches must be planned; heavy artillery forwarded; machine guns, tanks, and ambulances must be supplied; railroads and bridges must be built and rebuilt. Then the airplanes—each airplane draws upon the skill of all branches of engineering, provided as it is with guns, ammunition, engines, barometers, oxygen-producing apparatus, compasses, wireless telephones, etc. An eminent physicist recently told me, in speaking of the airplane, that a fully equipped airplane would be all that would be required for the proper equipment of a modern physicist's laboratory. Think of those marvels of engineering design—the modern warship, the submarine, the dirigible balloon, and the flying hydroplane. You will, I am sure, agree that modern war is impossible without the engineer and his work.

I was talking with an officer just back from the front who said that the work of the modern army was fully eighty per cent engineering, and that the importance of the work of the trained engineer in this war could not be exaggerated. I received the impression that the Allied army was not as well supplied with engineers as the enemy, and that our help would be doubly effective and welcome because it would supply this deficiency.

There is also an unlimited field for the effective use of all engineers in the important work behind the lines here at home—in the workshops, the arsenals, the chemical industries, and the thousands of industrial and engineering institutions demanding not only that they be kept going but extended to an unheard of degree in order that our army in France may be properly provisioned and equipped.

The growth of knowledge and the extension of scientific engineering activities have favored and even demand increased specialization. It is necessary if progress is to continue. There is no other way in which experience and knowledge can be increased.

Take for example, the profession of electrical engineering. There was a time when an active intelligent man could keep thoroughly posted as to the progress in all the fields of electricity. Up to 1880, it was easy to keep informed as to such progress, not only in this country but throughout the world. It has been increasingly difficult during the past twenty-five years, until today it is impossible to keep well posted as to even one of the many branches of electrical activities.

Now there is need for such specialization, as I have stated. I do not yield to anyone in admiration for the highly trained specialist or appreciation of the value of his work, but I do wish to point out some of the dangers of too great specialization.

It tends to produce a limited view, not only of one's profession but of life. It also leads to intellectual isolation; and to lack of efficiency, in a broad sense I would, therefore, like to see each specialist devote some of his time, not only to the study and appreciation of other fields of engineering and science, but to business, art, and politics; otherwise, his point of view will surely become pinched and distorted, and lacking in a proper sense of proportion. The result may be that the specialist eventually comes to have an exaggerated opinion of his own special work and a lack of appreciation of the work of others.

Now from the standpoint of the average man, an engineer is a specialist; and in order that engineers should take their proper place in the social organization and do their full duty as citizens, it seems to me that it is of the utmost importance that they should cultivate what may be termed a sense of proportion, discrimination, and good sense, often called "common sense." After character, success in life depends upon this quality more than upon any other, and it is essential for success in a professional career.

To illustrate: an engineer may be required to prepare a list of materials, with costs at current prices, for a given undertaking, say a building, a bridge, a dynamo, or other piece of machinery. Many times I have seen such estimates submitted, not only with the detailed items but the sum total carried out to the second and third decimal places, when the quantity involved was of the order of $10,000. This would be a commendable accuracy under some conditions, but when the natural variables in price, weight, etc., are known to be such as to make it impossible for the result to be accurate within five or ten per cent, such attempted accuracy is not only useless but ridiculous.

The same lack of a sense of proportion, or a fitness of things, may be shown in spending a large amount of time, money, and effort in elaborating unimportant details under conditions when the fundamental factors have not yet been settled, and when what is wanted is to determine the limits of the essential factors. So an elaborate calculation is an error when a simple one will suffice; a costly set of drawings is a grievous mistake when a rough sketch will answer the purpose; costly and elaborate tools for saving labor may prove useless because the amount of labor to be saved may be insufficient to even absorb the cost of the tools. Work done by hand may in many cases be more economical than that done by the aid of automatic tools. As the old copy-book maxim reads, "Circumstances alter cases," so we must never fail to consider the circumstances surrounding the problems which we intend to solve.

I think that specialization which is tempered by a lively interest in other things also leads to better work in the special field. The great discoveries and inventions which have revolutionized the world have been produced by men who were more than specialists. Bell, the inventor of the telephone, was not an electrical engineer but was a teacher and student of acoustics; Maxim, inventor of the Maxim gun, was an electrical engineer as well as a mechanical engineer; Wright, inventor of the flying machine, was a bicycle manufacturer; Thomson, inventor of electric welding, the arc lighting system, etc., was originally a chemist.

This is truly a land of opportunity, but there is also an old saying, "Opportunity has long legs and quick motions, therefore, embrace your opportunity," so we must have the wit to see an opportunity when it occurs and cultivate our sense of proportion so as to be able to discriminate between a good and a poor opportunity. This is where training such as you have had should be of great help, provided it is supplemented by hard work. Hard work and training will abolish hard luck; at least good luck usually comes to those who are not only looking for it but working and preparing for it.

There is a common idea that great inventions are the result of accident. This is not true. They may appear to be the result of accident, but the same accident may happen nine hundred and ninety-nine times to nine hundred and ninety-nine persons without suggesting or producing anything of value to the world, but to the one thousandth man who is ready and trained it may lead to an important discovery or invention. There are many illustrations of this.

The telephone is an example. Bell had been working on a multiple telegraph device for years, thinking at the same time of the telephone, but a lucky accident during a test led almost instantly to the invention of the telephone. Watson who was Bell's assistant at the time has testified that the accidental noise which Bell heard over the wire meant nothing to him, but to Bell it meant the key to the solution of the problem which he had long sought.

Specialization is indeed but a form of division of labor necessary to material progress, and with proper organization it increases the efficiency and total sum of useful human effort; but it obviously makes the individual unit more and more dependent upon other units for comfort and even for existence. It calls, with increasing force, for a better organization and better co-operation and co-ordination between all the different elements of society. The evolutionist calls this process adjustment to or correspondence with one's environment.

In the modern world, this means more than adjustment to one's immediate environment or profession, or of country, but extends to the world at large, at least a large enough portion of the world to make modern civilization possible.

However, specialization seems to lead either to an autocratic or to a democratic organization of society. The autocratic type of organization is of course illustrated by the German method where the directing and planning is done by a few self-appointed leaders.

In a democracy, which we believe to be the best organization of a people to insure an intelligent and happy existence, the thinking is not limited to a small class but must be indulged in by the mass of the people. The opinions of the mass are, of course, of controlling importance under a democratic system of government and eventually decide the fate of each member, including that of the specialist. Therefore, the views of the mass are of vital importance. It is for this reason that the specialist must give thought to other matters outside of his field, so that he may be fitted to influence the general viewpoint.

The effect of such interest and study of other matters will naturally be to enlarge his own viewpoint; improve his sense of proportion; teach him to co-operate with other specialists and workers in other fields; and this, in turn, will help to educate the world to a better appreciation of the specialist's work. It is a safe conclusion that if man is to progress as a civilized social being it must be as the result of the general diffusion of a sound, well-balanced education.

Germany illustrates the danger and the weakness of an unbalanced and unsound educational program. It is generally admitted that she fostered technical education, and that such education is perhaps more general there than in other countries. This, among other reasons, has helped her to great success in trade, manufacture, and commerce before the war, and up to date, in the war itself. Her weakness which will prove fatal in the end is that she has, in her educational formula, omitted altogether the existence of other human minds in the world outside of Germany. This is a species of super-specialization and has led to an exaggeration of the importance of German achievement in German eyes to a point of insanity.

The Germans have been systematically educated for years to regard the intelligence, ideals, and accomplishments of the rest of the world as so grossly inferior to their own as to justify an attempt to replace such inferior beings by Germans; so side by side with the arts of peace, the Germans developed the arts of war as no other people or nation has done; in fact, as we now know, all progress in science, industry, and commerce was made subservient to the preparation for war.

It was the secret motive behind the development of the chemical arts, of industry, of research, and of education; it was illustrated by the Zeppelin, and equally true of the adoption of the airplane. I was in Germany at the time when the Wrights sold their patents to a German company and was told at that time that, although this German company did not consider that the manufacture of airplanes would be a profitable branch of work for years, if ever, it was forced to go into their manufacture by the orders of the kaiser himself, merely because the airplane might be useful in time of war.

This horrible and systematic degradation of science and industry to the vile purposes of offensive war, this German kultur, was the fundamental cause of plunging the world into the present maelstrom of destruction. Now we are in a position where the peace-loving inhabitants of the world, including ourselves, have been forced to turn our energies into the manufacture of instruments of war; and, in general, organize ourselves for the one important business—that is, the killing of Germans. It must be done in self-defense, as the Germans have decided that there is not room enough on the earth for themselves and other nations, unless the other nations and people will bow the knee to Germany.

The extraordinary actions of the Germans may be due to a species of philosophical and educational fanaticism, developed to the point of insanity, a super-specialization directed by a bureaucratic and autocratic system of government. There can be no compromise with such organized and educated insanity. It must be overcome. Civilization may receive its death-blow in the attempt but it will be better to die in the attempt than to live in a world subjected to the rule of cruel and insane fanatics. The view that the Germans are insane fanatics is justified by the statements of their public men, for example, von Bethman-Hollweg is reputed to have said early in the war, "The rest of the world is full of devils and we must fight them." The constant reference of the kaiser to God as his partner is another notable instance.

Their systematic cruelty, total disregard of the laws of humanity and of civilization, and their defiance of the opinion of the civilized world best fits the theory of insanity.

While I have briefly mentioned what seemed to me to constitute some of the defects of our modern technical education and work, I have only done so because of my great anxiety that the technical man should fit himself to assume his rightful position in our political and social organization.

I am an enthusiastic believer in the vital importance of a more thorough understanding, by the majority of our people, of the ideals and practical value of science and engineering. To this end, it is essential that the general public should have a better and larger education in scientific matters.

There is nothing so dangerous as ignorance. If our people had been more extensively educated in science and engineering, we should not have been so slow to realize the dangers of this great war. The violation of Belgium and the sinking of the Lusitania would have given us ample warning of what was in store. We should have been spared the childish chatter about "a million men springing to arms overnight." We should have been able to comprehend that such a war, although 3000 miles away, was of vital interest to us and we should have got busy preparing for the inevitable conflict. We have been in this war now for one year. There is a deep disappointment throughout the country because we are not yet through mobilizing; because we are not yet able to help our Allies as we had hoped at this critical time.

Criticism is plentiful, both private and public. Criticism is healthful and helpful, if based upon facts; and if kept within the facts is reasonable, constructive, and patriotic; but much of the criticism we hear is unintelligent and is based upon ignorance of the stupendous nature of the problem.

This war is different from all previous wars, in that it requires for success the mobilization of the entire resources of the country. It is, in fact, a business and must be organized and run as a gigantic business, and yet it must be directed and operated by the Government. Now all existing business has been built up and run by private organizations. However, our executives and congressmen were not selected because they had demonstrated their fitness to operate large business. Successful business men, engineers, financiers, and merchants are not yet popular candidates for Congress and for executives.

If you wanted a navigator for a ship, you would not select a man who had never been on the water or aboard a ship. Orators may be good bankers, engineers, or merchants, but men who are selected to lead such enterprises are not selected by competition in oratory or literature. Therefore, if war is a great business, it is evident that, until the people through their representatives adopt business methods and put trained men who have won success in business in charge of this war business, it is idle to expect the maximum of progress.

Distrust of successful business men has been fostered by our politicians and it has taken a long time to bring about a change. Fortunately, the great American public is now aroused and is demanding the use of its best brains and brawn in the prosecution of the war. The great "ground wave" of public opinion has forced, during the past few months, a welcome increase in the admission of business men of proven ability into positions of importance. Such men are anxious to serve and the country demands that no more time should be lost in getting the right men in the right places.

It we were fighting a nation whose organization and experience were similar to ours, lost time would not be so serious; but our enemy has been organizing for generations and has had nearly four years' experience in this war, and she will not wait for us. She boasts that we cannot get into the war in time. Let us then stop useless criticism and get down to business, war business—not "business as usual" which nearly paralyzed England's original war efforts. There must be no limitations of effort, no limits of production, either here or "over there."

When the history of this war is written, after the conclusion of a victorious peace for our cause, I venture to prophesy that the future historian with all the facts before him will decide, as to America, that no matter how costly were all of the mistakes after we entered the war, in men and money, they were of trifling importance compared with our failure to prepare energetically for the war from the moment that Germany crossed the Belgium border. That historian will also have to decide who was to blame for that stupendous blunder—the people as a whole or its elected rulers. We cannot decide at this time, and a discussion of the matter is therefore unprofitable, except as a warning that we must now waste no more precious time but must work double time in the effort to make up for the time that has been lost

I envy you your youth and energy and your opportunities. You have an interesting future before you as engineers and inventors. Some "doubting Thomas" among you may say, "But all the great discoveries and inventions have been made; there is nothing more of importance to be discovered or invented." I am certain that your "doubting Thomas," if such exists, is wrong as was the "doubting Thomas" of old; and why, I will tell you.

I have been engaged in engineering work, mainly electrical, for nearly forty years, during which time the entire electrical industry may literally be said to have had its birth and development—the telephone, electric light, electric motor, trolley cars, wireless telegraphy, wireless telephone, electric transmission of power—all these have appeared since my first youthful venture in electrical work.

Now on a number of occasions, during these forty years, a lull in new inventions and discoveries seemed to have come about; and on such occasions I have talked with eminent engineers and inventors who all agreed that there was nothing more of importance in our line to be discovered. This conviction was strongest about thirty years ago; fairly strong about twenty years ago; a little weakened but still existing fifteen years ago, but now is a dead doctrine. I have had no such discussion for over ten years and do not expect to have another so long as I live, for facts have been against that theory, and of course facts are such stubborn things that theory which contradicts facts must be abandoned. Therefore, I say with confidence that a great future awaits you in your chosen profession; greater things are waiting to be discovered than are now known. There is no limit to man's mastery over nature's secrets, excepting his own limitations of time, and willingness to study, think, and experiment.

The great mission of science and engineering has been to uplift and benefit mankind. It is therefore the duty and high privilege of every scientific man and engineer to resent the degradation which Germany has placed upon our beloved profession. It remained for the Germans to systematically divert the discoveries of science to war's horrible purposes.

When the war is over, there is danger that many men and women, who are unscientific, will make the mistake of thinking that the terrible war was brought about by the German's devotion to science rather than by his degradation of science, and there might follow a reaction against science itself which, if successful, would plunge the world back into the darkness of the middle ages. It will be the duty of all scientific men, by education and example, to demonstrate that it was the abuse and not the use of science by Germany which was the cause of all our suffering.

It has been well said that "when the world has been made safe for democracy, democracy must be made safe for the world."

It is evident that a democracy founded upon ignorance and prejudice would be a sad reward for the world's agony. Such a disaster can happily be avoided by a general diffusion of a well-balanced education throughout the mass of the people; and in a well-balanced educational program, science, both pure and applied, must form the foundation. An ideal democracy can only exist when the Golden Rule governs the relations of its human units with each other and this fortunately would be the ideal atmosphere for the true followers of science.

It is unfortunate but it is true that we, who hate war with all our soul and with all our strength, must and will become the temporary but resolute instruments to punish the Germans who have been taught to love war and worship it as a religion. There is an impossible gulf set between our ideals of life and those professed and horribly practiced by Germany. The discoveries and inventions of science have made the world too small for both of these ideals to exist side by side—one or the other must perish from the earth.

We have full confidence as to the result. With right on our side we are mobilizing our mighty resources; and with the help of God and our Allies, will go forward to a glorious victory.

What We Must Do To Win the War*

By E. W. Rice, Jr.

President of the American Institute of Electrical Engineers; President of the General Electric Company

Mr. Rice again refers to the urgent need for every man, woman, and child in the country to do his utmost to assist the war efforts of the government. Most of us do not seem to realize the magnitude of the task that is ahead of us as individuals. Our leading engineers and business men have been the first to realize the great amount of hard work and sacrifice that will be demanded from every citizen, and it is they who are making appeals to the great body of our people to arouse themselves and come to a full realization of what we must do to win the war.—Editor.

No apology is needed in such a crisis in the world's history for talking about the war. It is impossible to cease thinking of the great drama now being enacted in France. Our fate as a nation and our ideals of life are all at stake; our personal liberties and lives are threatened; therefore, we are compelled to think of the war in proportion as we value our ideals in life and to the extent we realize our duty, if not our danger.

As thought should result in action, so it is useful for us to compare our ideals with those of our fellowmen. We are, therefore, justified in talking about the war, whenever we get together. The result of such discussion should be beneficial; it should help to bring about that unanimity of purpose and co-ordination of action which is absolutely essential to enable us to gain a victory over our enemies.

The reasons, the motives, and objects to be attained have all been stated many times by our official spokesman and leader, our President.

We are conscious that no nation ever drew the sword with greater justification or with greater reluctance.

We all regard war as a horrible thing which should be impossible as between cultivated and civilized nations. An offensive war is so wicked that any nation or people who start an offensive war must be regarded as outlaws and murderers. We did not start this war, it was forced upon us, and we therefore fight with a clear conscience. I hope we shall never stop fighting until we have accomplished our mission, which is, with the help of our Allies, to so crush our brutal enemy that he will never again be able to start a war of conquest.

While we all realize that we drew the sword in defense of our ideals, for which our Allies had been fighting over three long agonizing years, yet I sometimes wonder if we all realize, as we should, that we are now fighting for our own country and our own institutions. Do we realize that the defeat of our Allies would bring disaster to us, each and every one of us?

It is difficult to visualize events which are happening 3000 miles away. Engineers and inventors, whose trained minds should be able to clearly picture the situation and who should be able to appreciate the real danger, have a great responsibility. It is their duty to bring home to those whose knowledge of science and engineering is weak or absent, the true situation and the very real and terrible danger which threatens us. From this point of view, *it would seem as though America is only half awake; she must arouse herself to work, and work as she has never worked before in her history, if we are to win this war.*

A Tremendous Task

The task in which we are engaged is so tremendous that we must allow nothing to distract our attention from it. We must first of all get rid of the enervating thought which

*Delivered before the Pittsfield Section of the American Institute of Electrical Engineers, April 1, 1918.

would tend to paralyze our efforts, that this is to be a short war. We cannot have a safe peace until Germany is thoroughly whipped, and it must be evident by this time that Germany cannot be beaten until the United States adds her full military power to that of the Allies. We cannot expect to exert that full military power for a year or two years, even if we redouble our present efforts; therefore an early peace can only be considered a defeat for us and a German victory. So let us get out of our heads any idea of a short war and prepare for a long and bitter struggle.

Germany has boasted and still boasts that the war will be over before the United States can get into it. She bases her boast upon the fact that a large amount of time is required to put a nation on a modern war basis. She knows that we were unprepared when we entered the war. She knows that big guns, rifles, tanks, airplanes, trained soldiers, and ships cannot be improvised but must be built. This all takes time, even when the organization and manufacturing facilities already exist. Germany knows that many of these facilities did not exist when we entered the war, and while appreciating our potential strength, she believes that she can beat the Allies before the United States can put an effective army in France.

The collapse and surrender of Russia has given her an enormous advantage. She fears that the United States may be able to do something before next spring, and hence she is making a great exertion now. If the Allied line holds and we do our full duty, victory will finally rest upon our side. Are we doing our full duty?

Critics Don't Realize Task

We have been humiliated that at this time of stress we are unable to render assistance to our hard-pressed Allies, commensurate with our size and potential strength. There has been much criticism in Congress as the result. I think that much of the criticism, while entirely natural, is misplaced, and it is due to a lack of appreciation on the part of the critics of the magnitude of the task.

It is true that we have fallen far short of the advertised program; that many mistakes and false starts have been made. It is to our credit that we are disappointed over the small amount of assistance which we have been able to render to our Allies up to the present time. We should accept our humiliation, however, manfully, as a part of the punishment for our shortsightedness in not preparing to enter this war at a time when the violation of Belgium and the sinking of the Lusitania made clear the character and the intensions of our present enemy.

Whether the country would have supported its leaders in a vigorous effort to prepare for the war at such a time, if they had been so advised, no one is wise enough at the present time to state with certainty.

I do not mention this delay for the purpose of criticism but merely to point out the fact that this delay constitutes our real mistake. There is no use "crying over spilled milk," and it is only useful for us to keep this mistake in mind in order that we may avoid similar mistakes at the present and in the future, and realize more forcibly the necessity for strenuous effort in order, if possible, to make up for some of the lost time.

I think if we consider the enormous amount of work which has been accomplished since last April, that we shall be satisfied that, on the whole, we have made a good start. Those of us who have had any experience in manufacturing and engineering, especially on a large scale, have an appreciation of the difficulties required to build a large and successful engineering or industrial organization. We know by experience that such an organization requires, under normal conditions, many years to bring it to a successful and efficient operating condition.

The great industrial organization to which many of you gentlemen belong has been in existence for twenty-five years, and during all this period the men of its organization have been learning to work together and naturally have grown in experience and knowledge of each others habits, peculiarities, and qualifications. Many readjustments and adaptations have been found necessary during this long period in order to bring about that co-operation and "team-play" which is so characteristic of the organization and which is the cause of its success.

Entire Nation Must Respond

Now in ancient times, a great country could carry on a war without drawing very heavily upon the energies or resources of the nation. Modern war, especially this great war, as has been frequently stated, monopolizes the entire energies and resources of a country, if it is to be successful. It requires the organization of all the people into a great war machine. The entire industrial, transportation, and all other activities of the people must be co-ordinated and put to work on material needed for the war which, in most cases, is totally different from that with which they have already been accustomed. These changes consume time and create great confusion, and in addition, as is well known, it was found necessary to create new factories, warehouses, docks, shipyards, and other new vocations, of a magnitude unusual even in our country.

It is almost impossible for us to realize the magnitude of this task in the case of a country like the United States, of a hundred million people, scattered over an enormous area, and before the war completely devoted to the pursuit of the industries and the arts of peace, with no military training and with an instinctive dislike for war and its machinery. I venture the opinion that if the problem of organizing the country upon a war basis had been put into the hands of the ablest and the wisest men of the country that it would have been impossible to have produced by this time an entirely satisfactory and smooth-working machine. Time is required for such an accomplishment and this time is not to be measured in months but probably in years.

The Germans have had an enormous advantage over us in this respect as they have been organizing such a machine for forty years. Germany's military, naval, commercial, financial, and industrial organizations have been taught to co-operate and to work together as a war machine for many, many years. We all know what the conditions have been in this country. Instead of co-operation between transportation, industry, finance, and Government, there have been mutual lack of confidence and mutual ignorance and prejudice, not to put it too strongly.

We have plenty of strong men in all these various activities of the country, and I believe they now are and have been since the war started, patriotically endeavoring to co-operate, but in addition to the magnitude of the task, which I have already outlined, we have been handicapped by the lack of confidence between the various elements of our country, and even under pressure, confidence is a plant of slow growth.

The Big Job Sketched

Those of you who have read the address which Mr. Hurley recently gave in New York, describing at length the work of the Shipping Board, since he took charge, will remember he stated that he considered the organization and magnitude of the work was equal to double that of the United States Steel Corporation (our largest corporation), and Mr. Hurley's job, while most important and vital, is only one of the many tasks of similar magnitude which this country has undertaken to perform. We must bear in mind that these great organizations, such as the Navy, the Army, the shipbuilding, and the aircraft, must be co-ordinated and the work kept abreast in order that we may put and maintain an army in France which will be worthy of our country and necessary to win the war.

All thinking men admit that an autocracy which has the backing of its people trained for years to think alike and to "team-play" has an enormous advantage over a democracy in cases where united effort of the entire people is essential, as in the case of war. We must admit this, as it is self-evident, but we do not for this reason admit that an autocratic government is the best form of government. We must, however, bear in mind that the Germans take this point of view and are trying to enforce it by a brutal war upon the nations of the earth. Force must be met by force, organization by organization, and we must therefore temporarily adopt as far as possible autocratic government.

Such action, although necessary to the highest efficiency, is so repugnant to our ideals and to our training that we cannot easily or quickly reconcile ourselves to it. Is it not, therefore, evident that, in order to win the war, the democracies of the world must bring to bear an overwhelming force of material and men? We must plan that the odds are greatly in our favor, if we are to win against autocratic Germany. I think this is evident, but the realization of its truth should not discourage us but rather stimulate us all to greater endeavor. We must have an enormous preponderance in guns, in flying machines, in ammunition, in ships, in men, and in all the great machinery of war.

We are happily getting over the idea, which was certainly "made in Germany," and imported into this country, as well as into Russia, by Germany, that this is a rich man's war. I think this country has come to realize that the rich are patriotic and would have had everything to gain by keeping out of the war. It is certainly true that, if there were ever a war in our history which was for the benefit of all the people, it is this war

A Warning to Labor

I am glad to say that the intelligent workmen of this country, and of our Allies, seem to realize this fact more and more. If they have any lingering doubt, they have only to look to Russia to see what would happen if Germany were victorious. *You will remember reading that in Kiev, Narva, Reval, and other occupied cities of Russia, the Germans have established factories and that they are forcing the inhabitants to work; that the workmen are paid two roubles daily, as against twenty roubles in Petrograd; that instead of eight hours' work, the Germans exact ten hours' labor and enforce the strictest attention to the task at hand.*

While, as I have stated, it would seem obvious that the democracies of the world must bring an overwhelming preponderance of men and material to bear into this war so that the odds should be greatly in their favor, there is one most important direction in which we ought to prove superior to our enemies, and that is in the field of invention. One has only to look over a list of the inventions of the first importance which have revolutionized the conditions of life and increased the world's wealth, to see that the democracies of the world, and particularly the United States, have a superior standing to Germany. The sewing machine, the cotton gin, the steamboat, the typewriter, the incandescent lamp, the telephone, the telegraph, the flying machine, the submarine, the iron clad, to mention but a few, were all American inventions; while the steam engine, the locomotive, the automobile, wireless telegraphy, the dynamo, were the product of our European Allies. These facts should give us courage and should stimulate us to the greatest endeavor to discover and develop new methods to enable us to overcome our enemies.

We all agree that it is a terrible thing to devote the great talent of our inventors and our scientists to inventions for the destruction of human life, but this is not our fault. We are fighting a war in defense of science We must make use of all that she and her followers can give us, in order to overcome our savage foe.

Can Overcome U-boat

Germany did not invent the submarine but she has adopted and enlarged it, and put it to its most awful use in this war. The reason that the submarine has been so successful in its hellish work must be attributed to its invisibility. It attacks like a snake in the grass, unseen because of this invisibility. Make it possible to locate, with exactness, the position of any and every submarine, and the value of the submarine as a fighting device will disappear, because it will then be possible to undertake an offensive campaign which will quickly bring the submarine under control. It is well known that a submarine on the surface is a relatively poor fighting machine and easily overcome by destroyers or equivalent fighting vessels.

As the submarine was invented in America, it is fitting and natural that the methods for its destruction should also originate here. I am not in a position to tell you just what has been done along this line. I believe that enough progress has been made so that I can give you assurance that when the devices and methods already developed are systematically and extensively employed by our Navy and the British Admiralty, the submarine, as at present known, will be brought under control.

There are many other opportunities for the discovery and application of new engines of war which are under consideration, and which will undoubtedly be perfected in time to be of service. I confidently look forward to the fact that we are superior in inventive ability to add to the odds which I have stated we must have in our favor; but I said many months ago, when the war first started, we engineers must not permit the American people to think that the war will be ended by some great and marvelous discovery. This would tend to distract our efforts from the only known method—that of the utilization on our side of overwhelming man-power and material forces.

Yellow Peril Made in Germany

We used to hear some years ago of the "Yellow Peril," but as the years passed the "Yellow Peril" did not develop. It was evidently manufactured in Germany by the kaiser and his fellow-conspirators, with a view to destroying the growing friendship which he saw arising between England and the United States on the one side, and Japan and China on the other. The kaiser's effort fortunately failed and our friendship for our strong and faithful ally, Japan, has grown warmer, and our confidence in her integrity and ability has, if anything, been increased by the kaiser's dastardly efforts.

I have but lately returned from Japan and am glad to testify to the impression that she made upon my mind that she is a sincere supporter of the United States and the allied cause. I am sure that we must and can trust her to do her part in upholding the standards of civilization. Her enemies and detractors have pointed out that there are some features of her governmental organization which resemble Germany. This is superficially true, but she is in spirit and soul the antithesis of Germany. Her rulers and her people are saturated with the spirit of "Bushido" which is only another name for chivalry and honor.

No people have greater reason for a just pride in their past and in the progress which they have made in recent times in adopting and assimilating the distinctive features of our Western civilization. She has the railroads, the factories, the electric power plants, ships and shipyards, the army and navy, modern educational facilities, and all the complicated factors of a highly organized modern nation. In making the progress which has been the wonder of the modern world she has had the good sense and wisdom not to lose her head or her soul. The world is indeed fortunate that she is now ready, strong, and eager to contribute her share in this battle for the freedom of the world. We must trust her to do it well and unselfishly, and I believe we shall all be well satisfied with the result.

But if the "Yellow Peril" was invented in Germany and was, I believe, nothing but the kaiser's camouflage, the Prussian peril is a horrible reality which threatens to destroy the whole earth. We must arouse ourselves, get busy, keep busy, and never let up for an instant until we win a victory and rid the earth of this Prussian menace. It is a long, long job and a hard job, but it must be done. I believe that it will be done, but we must keep everlastingly at it. I would suggest as our slogan, "Hurry up; Hurry up; America!"

CHARLES A. COFFIN MADE *OFFICIER* OF THE LEGION OF HONOR

The cross of *Officier* of the Legion of Honor was conferred May 13th on Charles A. Coffin, former President of the General Electric Company and now Chairman of its Board of Directors. This decoration, which is next higher than that of *Chevalier*, was presented by M. Justin Godart, ex-Assistant War Secretary of France and also member of the Legion of Honor.

M. Godart, now in this country on a mission to inform us of the efficiency of the French army's medical service and to thank us for our contributions to the Red Cross and other organizations, brought with him a special commission from the French Government to bestow the honor of *Officier* of the Legion of Honor upon Mr. Coffin in recognition of his energetic work as head of the Franco-American War Relief Clearing House and of his active efforts to promote the establishment of scholarships in French universities for American students after the war.

Mr. Coffin succeeded Judge Robert S. Lovett as head of the Committee on Co-operation appointed by the Red Cross to negotiate with independent war relief organizations. In his capacity of member of the Executive Committee of the War Relief Clearing House, he has been very much interested and active in war service.

Charles A. Coffin, financier and manufacturer, was born in Somerset County, Maine. He was a manufacturer in Massachusetts prior to 1881 when, with others, he purchased the Thomson-Houston Electric Company. He was active in the management of this company which in 1892 became a part of the General Electric Company. Mr. Coffin was president of the General Electric Company from its organization until June, 1913, and since then has been Chairman of its Board of Directors.

Regenerative Electric Braking on the Locomotives of the C., M. & St. P. Ry.

By W. F. Coors

Butte Office, General Electric Company

From the standpoint of the practical operating man, the author explains the principles of regenerative electric braking on the Chicago, Milwaukee & St. Paul locomotives, and further explains the action of trains under various conditions using this feature. Specific comparisons of the operation of main-line trains by steam and electricity detail the points of advantage secured by the electrification of this mountain railway.—Editor.

The inherent working principle of direct-current regenerative electric braking is the maintenance of the voltage or electrical pressure of the regenerating machine higher than that of the distributing system to which it is connected, by an amount sufficient only to overcome the resistance of the circuit involved and to allow a flow of current which will be within the machine's safe capacity, or regulated within the limits of the duty required. Controlling the value of regenerated current in electric hoist or other stationary service is simplified where the voltage of the distributing system, the duty demanded, and the distance to the apparatus which may absorb the regenerated energy and consequently the circuit resistance are fairly constant. In railway service all these conditions vary in an irregular manner due to the movement of trains, variations of track gradient, and other conditions peculiar to train operation.

One of the important advantages of steam railway electrification, where heavy grades exist, accrues from regenerative braking in the fact that the locomotive not only holds the descending train at a uniform safe speed, but also changes the mechanical energy of gravity into electrical energy for pulling some other train; whereas in ordinary electric railway and regular steam practice this energy is dissipated in heating and wearing of wheels and brake shoes.

A simplified wiring diagram of the direct-current regenerative braking scheme used on the C., M. & St. P. electric locomotives is shown in Fig. 1. In braking operation, the exciter armatures are connected to the terminals of the traction motor fields, the line connections to the trolley being the same as for regular motor operation. If the exciter voltage is higher than the voltage drop across the motor fields, current will flow from the former through the latter, which is in addition to the current already flowing from the trolley wire during motoring. Since the traction motor armatures continue to revolve at practically the same speed as before, this exciter current is added to the motoring field-current, and the generated pressure of the traction motors will rise somewhat in proportion to the

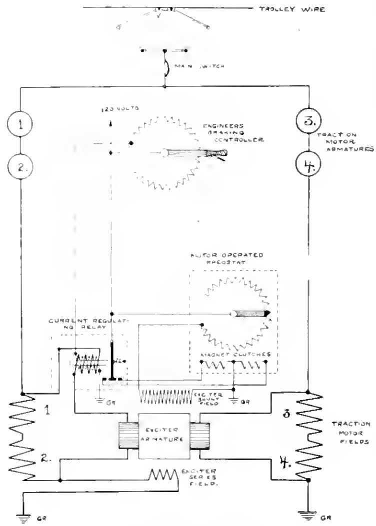

Fig. 1. Simplified Wiring Diagram of Regenerative Braking

additional excitation supplied. If enough excitation is added this pressure may be greater than that on the wire, and the current will tend to reverse its normal direction from the wire through the motors to the track, putting out mechanical energy, and flow from rail to wire requiring mechanical energy input to the motors running as generators.

On the other hand, if at the instant the regenerative braking connections are made, the exciter armature voltage is less than the voltage drop across the traction motor fields, a portion of the field current will flow through the exciter armature, which thus acts as a shunt. The traction motors, with less than their initial motoring excitation for a given speed, will necessarily have to revolve faster in order to regain their pressure balance with that on the wire. This action can only take place if the braking controller is applied when ascending a grade. If descending a grade, the train momentum may be sufficient to hold conditions fairly constant for a given excitation of the traction motor fields; otherwise their speed will decrease to the point where the generated pressure of the locomotive is less than that of the wire plus the resistance to the flow of current to a substation or another locomotive pulling a train,

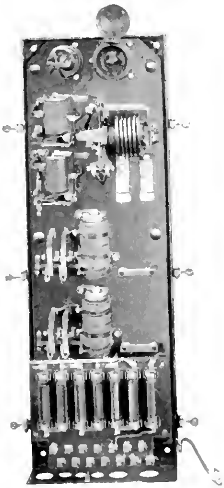

Fig. 2 Braking Current Regulating Relay

and the current will again flow in its normal motoring direction.

When the current has been reversed for braking, the exciter armature will carry the sum of the traction motor field and armature currents. Since the tractive effort is proportional to their sum, it may be seen that the power of the locomotive in holding the descending train may be regulated by increasing or decreasing the exciter voltage. The engineer has control over the excitation of this machine by means of the controller which

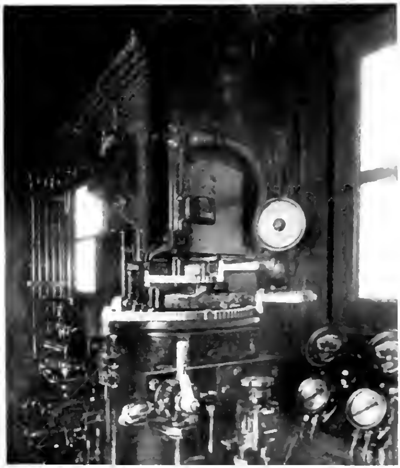

Fig. 3. Braking Controller

changes the setting of the braking current limit relay.

This relay (Fig. 2) operates at a definite spring tension setting which is opposed in its action on the relay armature by flux set up in the relay magnetic circuit by a series coil carrying the sum of the field and armature currents of one pair of traction motors and by a shunt coil supplied with variable voltage from the braking controller (Fig. 3). The relay armature carries two contacts similar in effect to a single-pole, double-throw switch each side of which is wired to a clutch magnet on the motor-operated rheostat (Fig. 4). This regulates the current in the exciter shunt field and consequently the exciter armature voltage. The small motor of this rheostat runs continuously while the regenerative braking controller is "on," and by means of magnetic clutches, may cause the motor operating through gearing to turn the rheostat arm in either direction of rotation, thus increasing or decreasing the resistance and current in the exciter field, depending on which clutch is energized by the separate contacts on the braking current limit relay.

The spring on this relay normally pulls the armature over to make contact for the magnet clutch that will cut resistance out of the exciter field circuit. This condition, when

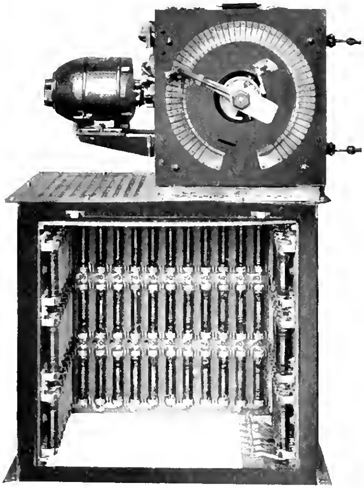

Fig. 4. Motor-operated Rheostat

braking is started, will then cause an increase in the exciter armature current flowing in the series coil of the regulating relay. When this current reaches a value sufficient to create enough flux to pull the armature away from the contact made by the spring, the motor-operated rheostat will come to rest. If the current increases further, the relay armature will be pulled over to the other contact, which will cause its magnet-clutch to cut resistance in the exciter field circuit and lower the current, so that a constant regulating action is obtained.

The shunt coil on the regulating relay is supplied by current, varying in value, from the braking controller, which is in effect a hand-operated rheostat. This shunt coil adds its magnetic flux to that of the series coil and therefore assists in overcoming the opposing spring tension. On the first position of the controller the current in the shunt coil is at a maximum, and therefore the relay will act at low values of current in the series coil. As the controller is advanced by the engineer this shunt coil current is lessened and the relay setting is increased until a position is reached where the shunt coil is de-energized and regulation is dependent wholly on the series coil. Further movement of the control reverses the current through the shunt coil causing its flux to oppose that of the series coil and increase the current at which the relay will balance. The shunt coil is gradually increased in strength in this direction until the same maximum is obtained as was used on the first notch, and this gives the maximum allowable regenerative braking effort of the locomotive. For ordinary changes of grade, speed and distance from substations, this action is fast enough to maintain uniform braking tractive effort. Moreover the exciter, being driven by a series motor, varies its speed and voltage with the trolley pressure, thereby requiring a minimum amount of work by the exciter field rheostat.

However, when a locomotive is generating power and the trolley voltage is suddenly decreased by another locomotive in the near vicinity starting a train, or ceasing regeneration, or is increased by another locomotive starting regeneration, it is evident that the pressure balance is likely to be upset on the locomotive in question, and more current may flow through the motors than is within their capacity if such an unbalancing is not quickly compensated for by the control apparatus. This condition is taken care of by the series field on the exciter which carries the line current and opposes in its effect the separate excitation of the shunt field. Therefore, any increase in this current will decrease the exciter voltage and traction motor field current, thus imposing a limit within safety. Or if the trolley voltage increases the generated current will decrease and the exciter voltage will rise, thus tending to hold the tractive effort constant. This protection from sudden voltage changes is further helped by the damping effort of the reactance of this circuit, and by the fact that the total locomotive voltage is made up of the two components, viz., the traction motor armature plus that of the exciter. This inherent regulation at low current values is also essential for protection from swings in line current when regenerating on light grades with long freight trains, in the prevention of cumulative train-slack surges. It also renders it possible to operate under conditions of grade such as tipping over the summit of a hill or level breaks in the regularity of the descending gradient, so that the locomotive can automatically change from motoring to braking with no change in its motor connections and no perceptible action on the train slack.

The motors are protected under exceptional conditions when regenerating, such as grounding of the trolley wire or opening of the substation circuit breakers, by over-load and over-voltage relays, respectively. A ground on the wire would cause a very large current to flow through the motors on a regenerating locomotive near at hand, and the overload relay should therefore act quickly to disconnect them from the line and kill their field excitation. If the circuit breakers at the substation are opened for any reason, or the wire or pantograph should break so that no path is left for the generated current, the voltage of the traction motors would rise excessively. This excess pressure is relieved by the over-voltage relay, which disconnects the motors from the line and kills their excitation. If the exciter motor should fail, the voltage of the control generator which is directly connected thereto will drop, thereby allowing the contactors to open and deaden all circuits. Three instances under extraordinary conditions may be cited to illustrate the working of the regulation equipment in actual operation.

When a passenger train was descending a grade and a freight train was ascending, the power was taken off the wire at the substations because of some wire trouble. The passenger locomotive on the down grade, generating power, pulled the freight up to the station where a meeting had been arranged, with nothing being noticed out of the ordinary on either locomotive until the latter arrived first at the switch and shut off power. There being then nothing to absorb the regenerated energy of the passenger train, the over-voltage relay acted, which was the first indication to show the engineer that anything out of the ordinary was taking place.

In another case a locomotive at a siding had a partly broken pantograph. This caused an arc from the roof of the locomotive to parts of the collector, which was still in contact with the wire. The engineer, for reasons of safety, had the power taken off at the substations so that he could untangle the damaged pantograph and disconnect it from the locomotive. The substation men acted quickly, but still the arc persisted for quite awhile as the engineer waited. Later, it developed that another locomotive descending the grade when the power was cut off had continued to generate current sending it into this arc at the damaged pantograph several miles away, without any indications of difficulty, this condition persisting until the engineer headed into a switch and shut off his controllers.

As an experiment, the braking controller of a locomotive descending a grade was set on the first step and the pantograph lowered from the wire, thus breaking connection with all outside sources of power. The locomotive then furnished its own energy for operating the motor-generators and air compressors, and the train was brought down the grade with the air brakes. In this case the exciter (on the motor-generator) and the locomotive were running when the pantographs were lowered from the wire. The exciters then furnished current for the traction motor fields, and the traction motors furnished current to drive the exciter. The speed of the motor-generator varied as the train speed, and the engineer controlled both by means of the train brakes.

The regenerative braking apparatus has no part in the regular motoring operation of the locomotive. Any failure in this apparatus itself leaves the locomotive ready to operate at full speed to its destination, the train being controlled with the air brakes on descending grades. On passenger locomotives the exciter is used for charging the train lighting batteries when it is not being used for braking. This requires only an additional switch for changing its connections. The exciter, which is driven by the motor-generator that drives the blower for ventilating the traction motors, requires little extra space.

In the parallel running position of the motoring controller, eight 1500-volt motors are connected to the line in four groups of two in series, and a practicable range of braking speed from 16 to 25 m.p.h. is available. In the series running position of the controller the eight motors are connected in two groups of four motors each and braking may be done at half speed.

Train handling during regenerative braking requires no more skill and practice by the engineer than that required in ordinary air-brake practice. Since all of the electric braking effort is exerted at the locomotive driving wheels the conditions obtain as if the locomotive air-brakes only were applied, leaving the train brakes running free, and quick slow-downs are not possible.

Therefore, long trains with several inches of free slack at each car coupler may suffer severe shocks on the head cars if the brakes are suddenly applied on the locomotive. For example, a freight train of 100 cars may have 70 ft. of "slack," and if this were all

Fig. 5. Ammeters Showing Degree of Regenerative Braking

"bunched" with the train at standstill, in starting up the locomotive would move 70 ft. before the last car in the train would be affected at all. If the train is running with all the slack stretched out and braking is suddenly applied on the locomotive, the cars tend to eliminate the free play in the coupling devices by bunching up hard against the locomotive, sometimes resulting in damage to equipment or telescoping weak cars which happen to be in the forward part of the train. However, if the braking is gradually applied on the locomotive this cumulative surge of train slack is avoidable and no severe shock will take place. Or if in descending a grade air-brakes are applied to the whole train, locomotive and cars, and then released gradually on the cars only, the slack will run in easily, the shock being "damped" by the slow release of the brakes. The locomotive will then hold the train after it has bunched and all brakes on the cars have been released. To accomplish this latter result "retainers" are utilized on the cars. These are small cocks which when "turned up" will hold about 15 lbs. per sq. in. pressure in the car air-brake cylinders, which leaks off very gradually, following a full application and "release" of the train-brakes from the locomotive.

Under ordinary airbrake operating conditions it is necessary to have retainers turned up on every car of a loaded train descending a long heavy grade in order to provide means of charging the brake pipe, without entirely releasing the shoes from the wheels and thus allowing the speed to get beyond control before the brakes can be applied again.

With this system of electric braking it is not possible to slow down to standstill, since at a certain low speed limit for a given value of field current, the voltage generated by the traction motors will be less than that on the trolley wire and motoring will take place. Moreover, since it is necessary to make motoring connections to the line before regenerating can be started, a certain amount of train slack will be pulled out first, to be compressed again when electric braking takes place. However, practical operation has shown that this action can be readily minimized and entirely neglected as far as effect on equipment is concerned.

With one locomotive in a train tipping over the summit of grade it is only necessary to keep the motoring controller "on" and advance the braking controller gradually as the descent is started. Each car will bring its own slack in gradually and no surges will be experienced. For each train of a certain weight on a given grade, there exist definite speed limits within which the locomotive can be controlled perfectly, as evidenced by the ammeters before the engineer (Fig. 5). All that is necessary to be done is to manipulate the braking controller according to changes in gradient or track conditions so that this limit is not exceeded, and so that the locomotive does not slow down to the point where motoring action will take place. If the speed increases for any reason above that value which will require more tractive effort than the safe current in the motors determines, the train air-brakes may be applied sufficiently for control, and regenerative braking continued at the same t me with no interruption.

The same method also applies to passenger and freight service when braking on gradients of about 1 per cent or less. When regenerative braking at half speed on light grades, it is sometimes necessary to first bunch and hold the train slack with the driver brake until regeneration can be started.

However, a slightly different procedure in starting is required when descending heavy grades with long freight trains and a stop has been made. In this case, with all the train on the grade, the engineer releases brakes and allows the train to drift up to a speed of about 20 m.p.h., and then applies the train brakes with the retainers turned up on about one-half of the cars on the head end of the train. Only a light application is made, sufficient to hold the speed momentarily while braking is started. The locomotive driver brakes are kept released and the motoring controller is advanced to the running position and the braking controller brought up slowly until the ammeters indicate reversal of current, when the train brakes are released. The engineer then holds the speed about constant by bringing on the braking controller as the retainers "leak off." Since the freight locomotive tractive effort rapidly diminishes at speeds much above the normal running value, very little slack is stretched in the train by this procedure and no shocks are perceptible.

Under most conditions of freight train movement a helper locomotive is used, both from braking current toward zero. When the current has been decreased sufficiently, he sets his automatic air brakes and throws off both controllers. As soon as the brakes slow down the train the helper's braking current falls off, and the controllers are shut off before the line ammeter needle passes the zero point and motoring begins.

Likewise with a helper, if a stop is made on a gradient of more than 1 per cent, regenerative braking is started under a slightly different procedure than when tipping over the summit. In this case the head man releases brakes and allows the train to drift up to about 20 miles per hour. He then applies the train brakes sufficiently to hold this speed for a moment while operating the controllers. As soon as they are set and the line ammeter begins to show braking current the brakes are released. The helper also

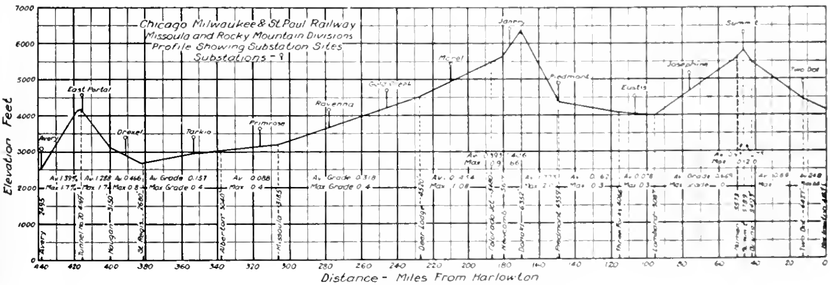

Fig. 6. Profile of Electrified Section C., M. & St. P. Rwy.

in ascending and descending heavy grades, in order to take full advantage of regenerative braking. Following the air brake test at the summit of the grade, the head man starts the train out just as if on the level. When the main controller has been set on parallel for full speed, or series for half speed, the braking controller is advanced notch by notch. As the speed comes up the line ammeter needle goes back to zero in the middle of the scale and gradually advances over the braking scale as the regenerated (reversed) current increases. The leading locomotive bunches the train slack back against the helper in the middle of the train, who then sets his controllers and holds back the train just enough to allow complete control by the man on the head end. In making a stop the head man eases off the braking controller and the line ammeter gradually returns starts to operate his controllers for regenerative braking as soon as the train brakes are first applied.

A profile of the present electrified section in Fig. 6 shows the three mountain ranges crossed by the railway. The Belt mountains are approached from Harlowton, going westward, by 35.7 miles of an easy up-grade, ranging to 0.6 per cent, as far as Lennep. Here the grade increases to about 1 per cent for 5.0 miles, until about two miles from the summit where a sharp grade of a little over 2 per cent is encountered going into Loweth. From this point to Lombard, 49.4 miles is a descending grade of about 1 per cent. From Lombard to Piedmont, 53.6 miles, is practically all water grade and no regeneration is practicable. With the exception of the short stretch of 2 per cent grade mentioned above between Bruno and Loweth, one electric locomotive will pull 2500 tons trailing load from Harlowton to Piedmont. And since the train friction is an aid to the locomotive, helping to retard the train during regenerative braking, trains of almost any size can be taken care of between these stations. It is customary for west bound full tonnage freight trains to "double the hill," from Bruno to Loweth on the 2 per cent grade. This means leaving half the train on the siding and pulling the rest up to the summit and then going down to get the other half. This is such a short grade that little time is lost in this way. East-bound freights on this grade having more tonnage than one locomotive will hold with electric braking, make free use of the air brakes.

From Piedmont to Donald is 20.9 miles, with a 2 per cent grade over the Rocky Mountains and Continental Divide, and two locomotives are customarily used on west-bound full tonnage trains averaging about 2500 tons each. East-bound trains of 2300 tons have been successfully brought down this grade with one locomotive regenerative braking, without using air-brakes and with about the same current in the motors that would be required for 1250 tons ascending the grade. However, some of this train was empty cars which have a high friction factor. With full loaded cars about 1750 tons trailing regenerative braking on this grade at 17–20 m.p.h. will require about the same current in the motors that 1250 tons loaded cars will in ascending at 15 m.p.h.

From Donald to Butte, 18.1 miles, is nearly all 1.6 per cent grade, and 1650 tons trailing east bound trains may be handled by one locomotive and 2500 west bound regenerative braking, although it is customary to keep the helper in the train which was used up the eastern side of the grade between Piedmont and Donald. Ordinarily east-bound trains are made up to 3000 tons at Butte for two locomotives.

Butte to St. Regis, 195.7 miles, is all descending grade with several short stretches of 1 per cent just west of Colorado Junction and 0.4 per cent to 0.6 per cent for long stretches. Almost any train which will hold together is hauled by one locomotive. Train length is usually limited by strength of draft rigging and safe operation of the air brakes, which get rather "ticklish" tending to "dynamite," or going into emergency application, and sticking on and generally refusing to operate according to rules and theory when more than 100 cars are hauled in a train.

From St. Regis to East Portal, 33.0 miles, the average west bound gradient is about 1.7 per cent ascending, over the Bitter Root Mountains, and from East Portal to Avery, 24.3 miles, about 1.7 per cent descending. Train loading generally corresponding to that on the west slope of the Rocky Mountains between Donald and Butte is followed here.

With steam operation the freight men met their hardest work on the severe grades, both when ascending and descending, but the passenger trains were always supplied with helpers under such conditions and were not hard to handle. Now the electrics go from one end of the section to the other and without having to stop for brake troubles and for coal and water, the schedules have been improved, and the maximum running speeds reduced.

The run up the slight grade from St. Regis to Butte under a fast schedule under steam passenger operation was a losing game when late, and speeds as high as 65 m.p.h. often had to be used. Now the electrics make the time easily and do not exceed 45 m.p.h.

The writer has ridden on a large oil burning steam engine pulling ten steel passenger cars from St. Regis to Deer Lodge 154.6 miles, when both injectors were used wide open to supply the boiler with water, the oil firing valve feeding all the fuel possible and the throttle wide open—and we made up just 10 minutes of lost time. No coal-burning engine could have even touched this performance, but the electrics exceed it so much every day that among the men fast runs or record hauls have ceased to be a subject of common conversation.

All the practical doubters who would not at first believe that an electric locomotive could control more tonnage at a safe speed on a descending grade than it could haul ascending, have vanished. There are no cases of overheated wheels. Passenger trains which required almost a complete set of new brake shoes after crossing the mountains and arriving at Deer Lodge, now go through with almost no shoe changing at all throughout the whole mountain section, and these savings are the practical results of regenerative electric braking.

Fundamentals of Illumination Design

Part II. ILLUMINATION DESIGN

By Ward Harrison

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The first installment of this series was devoted to a discussion of the fundamental concepts of the science of illumination, including units of measurement for intensicy, quantity of light, and illumination; methods by which these measurements are made; and the system of plotting distribution curves to show the characteristics of a given lighting source. The present installment deals with the diffusion of light, with special reference to defining the condition of glare; means of preventing glare and objectionable shadows; and the choice of lighting system, intensity, and the arrangement of lighting units. The principal types of Mazda lamp are listed and the characteristics of each are tabulated. The installment is concluded with a brief outline of the method of procedure for calculating any lighting installation.—Editor.

DIFFUSION OF LIGHT

In addition to a knowledge of reflecting surfaces and reflectors,* a knowledge of such factors as glare, shadow, and illumination of vertical surfaces—in a word, the diffusion of light—is necessary before an intelligent selection of a lighting system can be made. These factors all require most careful consideration if the best results are to be obtained.

Glare

By "glare" is meant any brightness within the field of vision of such a character as to cause discomfort, annoyance, interference with vision, or eye fatigue. Always a hindrance to vision, it often, like smoke from a chimney, represents a positive waste of energy as well. It is one of the faults most commonly found in all lighting installations.

A glance at the sun proves that an extremely bright light source within the field of vision is capable of producing acute discomfort. Light sources of far less brilliancy than the sun, such for example as the filament of a Mazda lamp or the incandescent mantle of a gas lamp, are also quite capable of producing discomfort by direct glare, but the annoying effect is not usually so marked. From our present knowledge, it appears that there are at least two distinct brightnesses which are of particular interest in connection with illumination problems. The more definite of these two is the brightness at which a given source looks just uncomfortably bright when viewed casually against a background. The second, and much lower value, is the brightness at which a source proves tiring and causes fatigue when continuously within the field of vision for a considerable period of time. The latter value is much more difficult to determine and it apparently varies through wider limits for different individuals. What these values represent may perhaps be more clearly understood by considering the analogous case of looking out of a window which by day is a source of light for a room. Unless the room is very dark or the landscape very brilliant, the effect of looking out of the window for a moment will not be at all unpleasant, but to sit all day facing the window would prove extremely tiring, even if one were sitting at a desk or table and not paying particular attention to the window. This is exactly comparable to the case of a light source which is not bright enough to cause an immediate sensation of glare but too bright to be viewed continuously. The problem of determining definite values for these two conditions of glare is rendered extremely difficult because of the fact that the extent to which glare is objectionable is partially dependent upon the contrast in brightness between the light source and the background. This is illustrated by the fact that although automobile headlights as seen at night against a dark background are likely to be so glaring as to be temporarily blinding, the same lights would in the daytime hardly be noticed. The permissible brightness of a light source is greater when the general illumination is of high intensity than when it is of low intensity. That is, for a room which has dark walls and furnishings, a unit of lower brightness should be used than would be permissible in a well illuminated room in which the decorations are light in color. The permissible ratio between source brightness and background brightness is not, however, constant; the ratio must be smaller at high values of intensity than at low ones.

The glare from street lights is often scarcely noticed as one walks along the street, but if one sits on a porch facing a unit, the glare is likely to cause acute dis-

* Part III of the series.

comfort. Such data as are now available indicate that ordinarily the brightness of a lighting unit which is in the central portion of the visual field should not exceed from 2 to 3 candles per square inch of apparent area, if that unit is not to give rise immediately to a sensation of glare, and the brightness should be reduced to 1/2 candle per square inch of apparent area if it is not to fatigue the eyes when viewed continuously. In this connection it is interesting to note that the brightness of the sky rarely exceeds 3 candles per square inch. A 200-watt Mazda C lamp in a 10-inch opal ball of medium-density glass will emit light at an intensity of about 180 candles (the opal ball so diffuses the light that the candle-power in all directions from the unit is approximately the same). The apparent area of a ball 10 inches in diameter is about 80 square inches, for as we look at such a ball from a distance we see a circular area of 80 square inches, which is acting as a source of 180 candles. In other words, the opal ball is a source emitting 2 1/4 candles per square inch of apparent area. Such a unit would be too bright for an office, but would be satisfactory for hallways, store rooms, and similar places which are used intermittently, and for a large proportion of stores and industrial plants where those using the illumination frequently move about and are not called on to face the lighting units for long periods. If a 60-watt lamp were substituted for the 200-watt in the 10-inch ball referred to, the brightness would be reduced to slightly over 1/2 candle per square inch, and this would usually be the largest lamp that could be used in a medium-density opal ball of this size if all danger of glare were to be avoided with the unit placed in an office or similar location.

It is sometimes possible to improve poor lighting conditions where the direct light from sources in the field of vision causes glare by changing the position of the sources. Little interference with vision is evident where light sources are 25 to 30 degrees away from the normal line of sight; but even when so located they are quite capable of producing eye fatigue if continuously within the range of vision.

A form of glare which is often less obvious than that which comes direct from the source to the eye, but which is frequently more harmful because of its insidious nature, is that which comes to the eye as glint or a reflection of the source in some polished surface. This form of glare, known as specular reflection or veiling glare, is frequently encountered where the work is with glossy paper, polished metal or furniture, or other shiny surfaces and is particularly harmful because of the fact that the eye is often held to such surfaces for long periods of time, and while the glare may not be sufficiently annoying to be recognized as of a serious nature, it may nevertheless in time produce eye fatigue or even permanent injury. Since the brightness of the reflected image is dependent upon the brightness of the light source, it follows that the harmful effects of specular reflection can be minimized by reducing the brightness of the light source. Frequently, specular reflections can be prevented from striking the eye by locating the light source in such a position with respect to the work that specularly reflected light will be thrown away from, rather than toward, the operator. The use of lighting units of large area and a diffusing medium to prevent any direct rays from the lamp striking the surfaces illuminated will aid in avoiding bad specular reflection; but on the other hand,

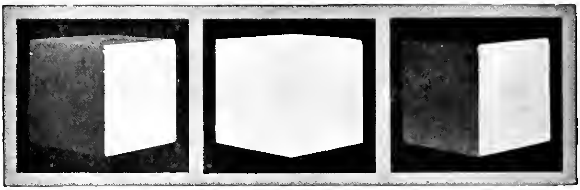


Fig. 13. A White Cube Lighted from Various Directions

if the source is very large, as, for example, a ceiling lighted by indirect units, a certain amount of specular reflection cannot be avoided. For a machine shop a more highly diffusing light source will be required than for a wood-working shop because the reflected images from metal are much more distinct than those from wood.

We see, then, that glare is a function of intrinsic brilliancy, candle-power toward the eye, distance, contrast, and proximity to line of vision.

Shadow

Shadows may be troublesome if they are sharp or so dark that it becomes difficult to distinguish between shadows and objects, or if the illumination in the shadows is insufficient for good vision. With general lighting, shadows from the work or fixed objects can be reduced by placing the units high and close together. A maximum degree of shadow results in the case of direct-lighting systems using unfrosted lamps in open reflectors of small area; a minimum in that of totally indirect lighting systems. Enclosing and semi-enclosing units produce shadows which are softer than those produced by open reflectors but much heavier than those produced by totally indirect systems. With semi-indirect units, almost any degree of shadow can be obtained by varying the density of the glass.

In observing objects in their three dimensions, shadows are an aid to vision in that the surfaces can be more easily distinguished from one another than if they are all lighted to the same intensity. Fig. 13, reproduced from photographs, shows the power of light to change appearance. However, while shadows are of great value in the discernment of irregularities of surfaces, they are of little or no value in the observation of plain surfaces. For example, while shadows are highly desirable in industrial work, in office work they are unnecessary, and, in fact, often a decided nuisance. With few exceptions, soft, luminous shadows only are desirable in interior lighting. Those having sharp edges or a series of sharp edges are objectionable.

Illumination of Vertical Surfaces

For many locations, such as offices and drafting rooms, light is required principally on horizontal planes, such as desk tops or table tops, and it has been the custom to calculate illumination on the basis of that delivered to horizontal surfaces with the assumption that the oblique surfaces of objects would be sufficiently lighted. This practice may result in inadequate illumination. In a machine shop, for example, the lighting of the vertical surfaces of the work or of machine parts is fully as important as the lighting of the horizontal surfaces. As a matter of fact, most shops are lighted during the day only by light from windows, which give a greater light on the vertical surfaces than on the horizontal. In all such cases where direct lighting is used, only those lighting units should be installed which show a reasonably good candle-power in the 50 70 degree zone as well as below these angles. A shop lighted by closely spaced automobile headlights directing the light downward from the ceiling would furnish ample light on a horizontal plane but such lighting would be far from satisfactory. The dome porcelain-enameled steel reflector gives the type of distribution desired for this purpose.

Desirable Wall Brightness

The effectiveness of a lighting system depends not only on the effectiveness of the lighting unit, but on the reflecting properties of the walls, ceiling, and surroundings, and upon the size and proportions of the room. It is, in fact, entirely possible to find an installation of reflectors of poor design and inferior from the standpoint of glare, which is nevertheless, from the single standpoint of the percentage of light reaching the illumination plane, better than an installation where reflectors of good design are used, if the former are installed under favorable conditions such as light walls, ceiling, etc., and the latter under unfavorable conditions. On the other hand, it must be borne in mind that a large expanse of wall surface finished so light as to reflect a large volume of light into the eye is objectionable for offices, residences, and all rooms where the occupants are likely to sit more or less directly facing the walls for considerable periods of time. Such data as are available indicate that where the brightness of the walls is equal to, or greater than, the brightness of white paper lying on a table or desk, annoying glare will result. In fact, a wall brightness one-half that of the paper has been found unsatisfactory; a brightness of 20 per cent is, apparently, comfortable. With the usual types of lighting units, walls are not illuminated to intensities as high as those obtaining on desk or table tops, and walls which reflect less than 50 per cent of the light which strikes them should not produce discomfort, providing, of course, that they are of a mat or semi-mat finish. Walls finished in buff, light green, or gray reflect about the proper proportion of light and their use is meeting with general favor. Walls finished in a high gloss are not satisfactory from a glare standpoint.

Definite values for the efficiency of different types of units as they are used in practice are presented a little later in this bulletin.

CHOICE OF LIGHTING SYSTEM

As already mentioned, there are three general systems of illumination which have come to be classified in accordance with the manner in which the light is distributed:

1. Direct-lighting systems;
2. Indirect-lighting systems;
3. Semi-indirect lighting systems.

Direct-lighting systems employ units which send the light direct to the surfaces to be illuminated. Reflectors or enclosing glassware are used to improve the distribution of the light and to diffuse the direct rays from the lamp, and to increase the apparent size of the source. With open reflectors, both direct glare from the lamp and glaring reflections are minimized by frosting the lamp and by the use of a reflector of large area. This will also have the effect of softening the shadows. Illumination of vertical surfaces can be accomplished by selecting a unit which has a distribution of light which is not too concentrating.

Indirect lighting utilizes the ceiling and walls for the redirection and diffusion of all of the light emitted by the units. Since the ceiling acts as the light source, with the maximum distribution directly downward, glare from the unit is avoided, and shadows are soft, but for a given illumination on horizontal surfaces there is usually less illumination on vertical surfaces than with other systems. For some locations, shadows are not sufficiently defined to be of much assistance in the discernment of small surface irregularities.

Semi-indirect lighting furnishes a means of combining the features of the direct and indirect systems. With a correctly designed bowl of dense-opal glass, brightness of the unit is low enough to avoid eye fatigue, and sufficient direct light is emitted to produce the proper degree of vertical illumination and the soft or graded shadows often desired. A light-density opal may be used in certain locations where the units are hung high and the nature of the work is such that the units are not in the usual range of vision.

The individual characteristics of the place to be lighted are important factors in the selection of a lighting system. The presence of large quantities of dust usually discourages even a consideration of indirect and semi-indirect systems for industrial lighting. The dark tone of the walls and ceiling in factories also often precludes the use of other than a system of direct lighting. Cost and efficiency are factors which may limit the choice, although the present tendency in industrial lighting, particularly in the more specialized manufacturing branches, is to make good lighting the first consideration. It may be mentioned in connection with lighting that the liberal use of paint or whitewash can hardly be too strongly recommended.

In residence, store, office, and public-building lighting, the system should, of course, be of good appearance and in harmonious relation with the decorative and architectural features of the surroundings. Semi-indirect and enclosing units lend themselves most readily to these classes of service if the color of the ceiling and walls permits their use. It should always be borne in mind, however, that such units to be satisfactory as to glare must be selected with care in accordance with the suggestions previously given. Totally indirect units, on the other hand, are practically certain to be satisfactory from this standpoint.

Aside from the renewal of lamps, and breakage, depreciation of the light output of a unit due to the collection of dust is usually the largest item to be considered from the standpoint of maintenance. It is evident that lighting units which have concave reflecting surfaces opening upward will collect dirt much more quickly than if the surfaces opened downward. The contour should be simple and the exposed surfaces smooth in order to expedite frequent cleaning of the units.

From the many lighting units on the market, a selection of a certain unit should first be made on a basis of its characteristics with regard to absence of direct glare, glaring reflections, and sharp shadows, the nature of its light distribution as adapted to the possible spacing and hanging height, and the illumination of vertical surfaces if the work demands it. The considerations of appearance, efficiency, maintenance, and cost will then determine which unit to select.

CHOICE OF INTENSITY

The eye is capable of adapting itself to see under illumination intensities which range from a small fraction of a foot-candle to several thousand foot-candles in value. At very low intensities the eye does not receive sufficient light to enable it to distinguish color or detail, and at very high values, a blinding effect which also obliterates detail is experienced. Between these limits there is a wide range of intensities where good vision is possible. Considerations of economy usually limit the intensities employed in artificial lighting to the lower values of this range. So closely is the lower limit approached that it is necessary in designing a lighting installation to take into consideration such factors as the color of the objects requiring illumination (for objects are seen by the light which they reflect, and dark objects require higher intensities than light ones for equally good vision); the order of brightness of surroundings; the amount which it is considered expedient to apportion for the advertising value of a high intensity; and the intricacy of the work which is performed under the artificial lighting. For example, a jewelry store in a small town may be brightly lighted at an intensity of 4 foot-candles, whereas a jewelry store located on a prominent business street in a large city will require, to be considered well lighted, an intensity of perhaps 6 or 8 foot-candles. Again, the cloak and suit department of a large store will require a higher intensity than will the white goods department. An industrial plant engaged in rough-box manufacture would be well lighted at an intensity of 3 foot-candles; in a high-grade machine shop an intensity as high as 6 or 8 foot-candles would be desirable. The values given in Table I have been established by experience and used by various authorities as standard in current practice. Bearing in mind the character of the work, the fineness of detail to be observed, and the standard of lighting of the immediate surroundings, one should be able to select a suitable intensity from the range of intensities given to serve as a basis for illumination calculations. It should be remembered, though, that the intensity so chosen can rarely be exactly provided in practice, and it should be con-

TABLE I

PRESENT STANDARD OF ILLUMINATION

		Foot-candles
AUDITORIUM, CHURCH		1.5 - 3
ARMORY, PUBLIC HALL		2 - 4
SCHOOL	Class Room, Study Room, Library	3 - 6
STORE	Show Window	10 - 50
	First Floor Department, Shop on Bright Street or Corner	7 - 10
	Other Clothing, Dry Goods, Haberdashery, Millinery, Jewelry, [illegible]	4 - 7
	Other Drug, Grocery, Meat, Bakery, Book, Florist, Furniture, [illegible]	3 - 5
OFFICE	Private, General .	4 - 8
	Drafting Room .	8 - 12
INDUSTRIAL*	For Rough Manufacturing Occupations, such as Rough Assembling, R[illegible] Forging, Rough Woodworking, Ice Making; [illegible], Lumber Mills, [illegible]neries, etc., etc. . .	2 - 4
	For Medium Manufacturing Occupations, such as Medium W[illegible] Rough Machining, Rough Bench Work, Automatic Machine W[illegible] Packing, Paper Making; Laundries, Bakeries, [illegible]	[illegible] 5
	For Fine Manufacturing Occupations, such as Fine Assembling, [illegible] Working, Fine Woodworking, Fine [illegible] Work, [illegible] Manufacturing, [illegible] Fine Sheet Metal Working, Manufacturing Light [illegible]	4 - 8
	For Extra Fine Manufacturing Occupations, such as Wa[illegible] Manufacturing, Engraving, Type Setting, [illegible] Manufacturing Dark-colored Textiles, [illegible]	[illegible]
BUILDING EXTERIOR		[illegible]5

*It must be remembered that, other things being equal, work [illegible] sidered simply as an assumed desirable value which permits the calculations to be carried through.

The average light output of Mazda lamps throughout rated life is about 94 per cent of the initial value, and the collection of dust on the lamps and reflectors in service will produce an additional loss of light, the amount depending upon the frequency of cleaning and the conditions of service. Open reflectors cleaned at regular intervals of from two to six weeks ordinarily show a loss of from 5 to 20 per cent at the end of the period. Experience has shown that an increase over the desired average intensity of 20 per cent may be taken to cover both the decrease in lamp output and the dust depreciation for usual conditions; in a foundry, or a roundhouse, an increase of 40 per cent would not be excessive. Since the actual intensity received from a lighting system should average not less than the value selected from the table the value selected should be multiplied by a "depreciation factor" of from 1.20 to 1.40, depending upon existing conditions, in order that the decrease from the initial intensity will not cause the average intensity to fall below the desired value.

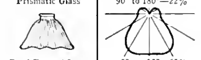
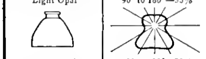
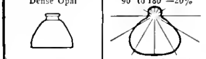
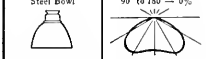
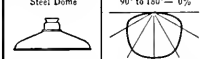
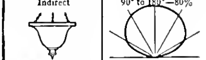
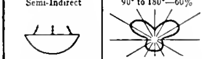
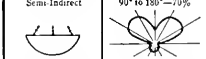
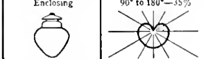
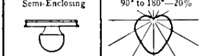
COEFFICIENTS OF UTILIZATION

Due to the loss of light through absorption by the reflector or enclosing glassware, by the fixture, and by the walls and ceiling, only a part of the total light emitted by a lamp reaches the designated plane. Of the light sent in directions other than those where it is used, some will be redirected by the ceiling, walls, and other surfaces on which it falls, and the percentage of the total lumens emitted by the lamp which ultimately reaches the desired location will, therefore, vary widely with the proportions of the room and the nature of the surroundings. Contrary to the general belief, the absolute height in feet at which units are mounted has in itself no influence upon the percentage of light utilized, so long as the same proportions are maintained. For example, if there are two buildings, one 20 feet by 50 feet and 10 feet in height, and the other 40 feet by 100

TABLE II

COEFFICIENTS OF UTILIZATION

This table applies to installations in *square rooms* having sufficient lighting units symmetrically arranged to produce reasonably uniform illumination. To obtain the coefficient for any rectangular room, find the value for a square room of the narrow dimension and add one-third of the difference between this value and the coefficient for a square room of the long dimension.

Reflection Factor: Ceiling			Light 70%			Medium 50%		Dark 30%
Reflection Factor: Walls			Light 50%	Medium 35%	Dark 20%	Medium 35%	Dark 20%	Dark 20%
Reflector Type	Light Output	Ratio = Room Width / Ceiling Height						
Prismatic Glass  Bowl-Frosted Lamp	90° to 180°—22% / 0° to 90°—65%	1 1½ 2 3 5	.42 .50 .56 .63 .70	.38 .46 .52 .59 .66	.35 .43 .49 .55 .63	.36 .44 .50 .56 .63	.34 .42 .47 .53 .60	.33 .41 .45 .51 .57
Light Opal  Bowl-Frosted Lamp	90° to 180°—35% / 0° to 90°—50%	1 1½ 2 3 5	.31 .37 .43 .49 .56	.27 .33 .39 .45 .52	.24 .30 .35 .41 .48	.24 .30 .34 .39 .45	.21 .27 .31 .36 .42	.18 .24 .27 .31 .36
Dense Opal  Bowl-Frosted Lamp	90° to 180°—20% / 0° to 90°—60%	1 1½ 2 3 5	.41 .49 .54 .60 .67	.37 .45 .50 .56 .63	.34 .42 .47 .53 .59	.35 .43 .48 .53 .59	.33 .41 .46 .51 .57	.32 .39 .44 .49 .54
Steel Bowl  Porcelain Enameled	90° to 180°— 0% / 0° to 90°—65%	1 1½ 2 3 5	.38 .45 49 .54 .59	.36 .43 .47 .52 .57	.34 .41 .45 .50 .55	.35 .42 .46 .51 .56	.33 .40 .44 .49 .54	.33 .40 .44 .49 .54
Steel Dome  Porcelain Enameled	90° to 180°— 0% / 0° to 90°—80%	1 1½ 2 3 5	.43 .52 .57 .63 .69	.40 .49 .54 .60 .66	.38 .47 .52 .58 .64	.39 .48 .53 .59 .65	.37 .46 .51 .57 .63	.37 .46 .51 .57 .63
Indirect  Mirrored Glass	90° to 180°—80% / 0° to 90°— 0%	1 1½ 2 3 5	22 .27 .31 .36 .42	.19 .24 .28 .33 .39	.17 .22 .26 .31 .37	.14 .17 .20 .24 .28	.12 .15 .18 .22 .26	.07 .09 .11 .13 .16
Semi-Indirect  Light Opal	90° to 180°—60% / 0° to 90°—25%	1 1½ 2 3 5	.27 .34 .39 .45 .51	.24 .30 .35 .41 .47	.21 .27 .32 .38 .44	.20 .25 .29 .34 .40	.17 .22 .26 .31 .37	.14 .18. .21 .25 .29
Semi-Indirect  Dense Opal	90° to 180°—70% / 0° to 90°—10%	1 1¼ 2 3 5	.24 .30 .31 .39 .45	.21 .27 .31 .36 .42	.19 .24 .23 .33 .39	.15 .20 .23 .27 .32	.14 .18 .21 .25 .30	.10 .13 .15 .18 .21
Enclosing  Light Opal	90° to 180°—35% / 0° to 90°—40%	1 1¼ 2 3 5	.23 .30 .35 .41 .48	.20 .26 .31 .37 .44	.17 .23 .23 .34 .41	.13 .24 .28 .33 .39	.16 .21 .25 .30 .36	.14 .19 .22 .26 .31
Semi-Enclosing  Opal Bowl	90° to 180°—20% / 0° to 90°—60%	1 1½ 2 3 5	.32 .40 .45 .52 .59	.28 .36 .41 .47 .54	.26 .33 .38 .44 .51	.27 .34 .39 .45 .51	.25 .32 .37 .42 .48	.23 .30 .35 .40 .46

feet and 20 feet in height, it is clear from Fig. 14 that the effective and hence the efficiencies of the lighting systems in the two buildings will be the same. If the small building is illuminated by 8 100-watt lamps on 10-foot centers and the large building by the same number of 400-watt lamps on 20-foot centers, the average intensity of illumination will be the same,* and its distribution will be similar. On the other hand, the *proportions* of a given building or room have a very important bearing upon the percentage of light utilized. In Table II are shown the coefficients of utilization, as the percentages are called, for the more common reflecting equipments when used in square rooms. For rooms in which the ratio of width to ceiling height is small, a low utilization obtains because, as shown in Fig. 15, a relatively greater portion of the light strikes and is absorbed by the walls than is the case for a large room. For rooms of sizes between the limits specified, proportionate values should be used; where the room dimension exceeds five times the ceiling height, the increase in the coefficient is so slight as to be negligible, and the coefficient for a ratio of 5 should be used. For rectangular rooms, the coefficient of utilization may be obtained by finding the coefficient applying to a square room whose ratio of width to ceiling height is equal to the ratio of the narrow dimension of the rectangular room to its ceiling height, and adding to this value one-third of the difference between it and the coefficient applying to a square room whose ratio of width to ceiling height is equal to the ratio of the long dimension of the rectangular room to its ceiling height. For example, the coefficient of utilization applying to dome-shaped porcelain-enameled steel reflector units used in a mill room with dark ceiling and walls 30 feet wide by 150 feet long with a 30-foot ceiling is found as follows: The coefficient for a room 30 feet square and 30 feet high is 0.37; the coefficient for a room 150 feet square and 30 feet high is 0.63; the coefficient for the room 30 by 150 and 30 feet high is then $0.37 + \frac{1}{3}(0.63 - 0.37) = 0.456$ or, in round numbers, 0.46. It should be noted that this figure is not the same as would be obtained by finding the coefficient applicable to a single square room of equal area, or to a single square room whose length and breadth are equal to the average of the length and breadth of the rectangular room.

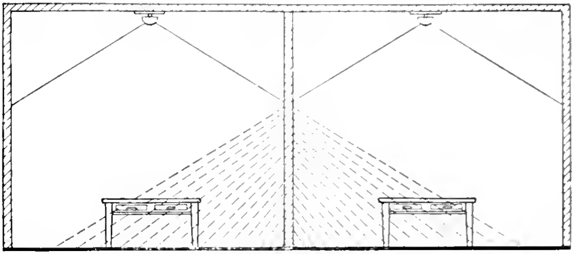


Fig. 15 The Coefficient of Utilization is Dependent upon Room Proportions. The Light Striking the Partition is Largely Lost

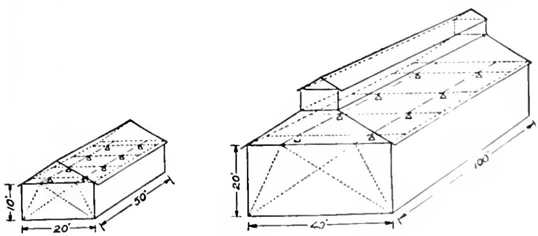


Fig. 14. Illustration of Effective Angle

The total lumens required for any room is, then, the product of the desired intensity in foot-candles and the area of the surface to be illuminated in square feet divided by the coefficient of utilization. It should be remembered that the value for the desired intensity should be multiplied by a depreciation factor of from 1.20 to 1.40 in order to insure an average intensity in service equal to that originally chosen.

*Neglecting the difference in the efficiency of the units.

LOCATION OF LIGHT SOURCES

From an analysis of distribution curves of the different units, fairly definite ratios of maximum spacing distance to hanging height which will insure a high degree of uniformity in illumination have been determined for various classes of reflecting equipment. Table III, with its footnotes, presents values which may be used with the knowledge that if the ratios are not exceeded, uniformity of illumination will result. It may be emphasized at this point that *closer* spacings than those calculated can be used without hesitancy; uniformity of illumination will suffer only from too great a distance between units, never from too little. Although units are obtainable which give a high degree of uniformity with wider spacings than those given for the units listed in the table, the long heavy shadows which result from units widely separated discourage the use of wide spacings in interior lighting. On the other hand, in many locations, as a restaurant, ball-room, or the home, uniformity of illumination and absence of shadow are not only unnecessary but actually undesirable, and in such places "rules" are, of course, to be disregarded.

In many cases, the construction of a building divides it into a number of bays, and, for the sake of appearance, the units should usually be placed symmetrically in these bays if compatible with uniformity of illumination. Panel designs on the ceiling, or other decorative features, also call for a symmetrical spacing, but it must always fall within the limits of the table with regard to the height of the units above the working plane if uniformity is desired. When there are no natural divisions in the room, and the outlets are not already placed, the room should be divided into a number of areas approximately square, and the units placed at the center of each, the maximum distance between units falling within the limits of Table III. With such a location the distance from the nearest row of units to the wall is one-half the spacing distance; the distance of the units from the walls may sometimes, however, be made somewhat less than half the spacing distance in order to avoid shadows and to maintain a high intensity close to the walls.

TABLE III

RECOMMENDED MAXIMUM SPACINGS AND MINIMUM MOUNTING HEIGHTS FOR VARIOUS UNITS

(Mounting height equals distance of light source above plane of illumination)

Equipment	*Ratio = $\frac{\text{Spacing}}{\text{Mounting Height}}$	†Ratio = $\frac{\text{Mounting Height}}{\text{Spacing}}$
Prismatic, Mirror, or Aluminum		
Intensive	$1^1/_2$	$^2/_3$
Focusing	$^3/_4$	$1^1/_3$
Extensive	$1^2/_3$	$^3/_5$
Indirect or Semi-indirect	$1^1/_2$‡	$^2/_3$‡
Opal or Porcelain Enamel		
Bowl	$1^2/_3$	$^3/_5$
Dome	$1^2/_3$	$^3/_5$
Totally Enclosing Glass	$1^2/_3$	$^3/_5$
Semi-Enclosing	$1_1/_2$	$^2/_3$

*To get maximum spacing distance, multiply ratio by mounting height
†To get minimum mounting height, multiply ratio by spacing distance.
‡Height equals distance between ceiling and plane of illumination.

The mounting height, it should be noted, is the vertical distance between the working plane and the lamp—not the distance between the floor and the lamp—except for indirect and semi-indirect systems, in which cases the height is the distance between the working plane and the ceiling, for with such units the ceiling acts as the light source. The use of a larger number of units than is required for the limiting spacing as previously mentioned does not detract from the uniformity of illumination; the considerations of higher costs for the equipment, as well as the arrangement and shape of the room, will usually be determining factors.

MAZDA LAMPS

Multiple Mazda lamps for use on 110–125 volt lighting circuits range in size from 10 to

1000 watts. The light output in lumens ranges from 75 to 18,000. The many sizes in which these lamps are available and their simplicity of installation and operation go far toward making them a universal illuminant. Typical Mazda lamps are shown in Fig. 16.

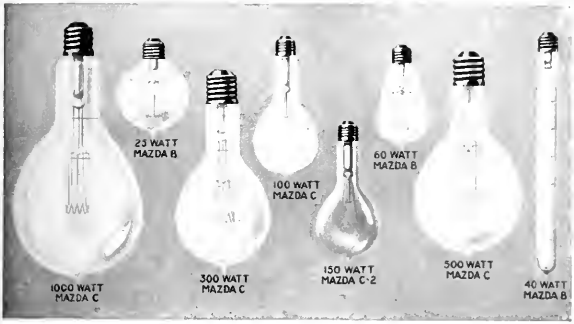


Fig. 16. Typical Mazda Lamps

In the smaller sizes, Mazda lamps are regularly manufactured in either round or straight-side bulbs; with modern reflecting equipment, however, the straight-side lamps are used almost exclusively. Lamps larger than 100 watts are standard only in pear-shaped bulbs.

Mazda lamps designed for operation on 110–125 volt circuits up to and including the 60-watt size are all of vacuum construction and are known as Mazda B lamps. There is also available a 100-watt Mazda B lamp. Mazda C lamps, which employ an inert atmosphere within the bulb to permit more efficient operation, are made in sizes ranging from 75 to 1000 watts. In these lamps the filaments operate at a higher temperature, and a comparison of a Mazda B and a Mazda C lamp will show that the light of the latter is noticeably whiter. Mazda C-2 lamps are available in sizes ranging from 75 to 500 watts. These lamps employ a scientifically selected blue bulb which screens out a portion of the red and yellow rays and transmits a light of afternoon sunlight quality. Mazda C-2 lamps are especially adapted to those many places and occupations where light of approximate daylight quality is desirable and where light of true north sky quality is not required.

In Table IV are given the light output in lumens and other data applying to the more common Mazda lamps of the 110–125 volt class. Attention is called to the fact that lamps of the 220–250 volt class are less efficient than those for 110–125 volt service. For this reason, and because of the fact that 220–250 volt lamps are more expensive and less satisfactory in service, the use of 110–125 volt lamps is recommended in all but very exceptional cases.

METHOD OF PROCEDURE

The problem which confronts the engineer designing illumination is to secure from the available lamps and reflecting equipment light of the proper quality and quantity and to distribute this light with a proper degree of uniformity. This involves, first of all, the selection of a type of reflecting equipment—direct, semi-indirect, or totally indirect—which will give the proper quality of light for the purpose at hand. The next step is to decide from a survey of the existing conditions and from data such as are given in Table III, what groupings of units—numbers of units and their location—will provide a satisfactory degree of uniformity. It will sometimes be found that the choices are closely limited by the structural features of the room or building. In such cases, the problem is only one of selecting a size of lamp which will supply the required intensity. In other cases, a choice of several arrangements of outlets is afforded, and here the problem is to determine which arrangement, in view of the lamps readily available, can best be employed to fulfill the requirements.

The lumens which the lamps must furnish initially are calculated by multiplying the area in square feet of the room to be lighted by the intensity desired for the particular purpose, multiplying this product by a depreciation factor as previously explained, and dividing the final product by the coefficient of utilization determined from a consideration of the type of unit, the nature of walls and ceiling, and the proportions of the room to be lighted. The number of lumens each lamp must give is determined by dividing the total lumens by the number of lamps it is desired to use. The relations may be expressed in the following simple equation:

$$\frac{\text{Desired Foot-candles} \times \text{Depreciation Factor} \times \text{Area in Square Feet}}{\text{Coefficient of Utilization} \times \text{Number of Outlets}} = \text{Lumens per Outlet}$$

From Table IV, a size of lamp can be selected which will give the required number of lumens. In case the location of outlets is closely limited by structural features, it will be necessary to make a choice between a size of lamp which will provide a lower intensity than that assumed as a basis for calculation and one which will provide a higher intensity. In such cases, the choice is not simply between a slightly higher expense than originally planned and a slightly lower one, but between a system which will prove adequate illumination and one which may not; when it is considered how closely artificial lighting intensities approach the lower limit at which good vision is possible, it will be seen that the safest course is to

TABLE IV

TECHNICAL DATA ON 110–125 VOLT MAZDA LAMPS

Watts	Total Lumens	Watts Per Spherical Candle	Lumens Per Watt	Bulb Diam. in Inches	Maximum Over-all Length, Inches	Light Center Lehgth, Inches	Base	Position of Burning	Rated Average Life, Hours
Straight-side Mazda B Lamps									
10	75	1.67	7.52	2 1/8	4 5/8	2 7/8	Med. Screw	Any	1000
15	128	1.47	8.55	2 1/8	4 5/8	2 7/8	Med. Screw	Any	1000
25	230	1.37	9.17	2 3/8	5 1/4	3 1/4	Med. Screw	Any	1000
40	378	1.33	9.45	2 3/8	5 1/4	3 1/4	Med. Screw	Any	1000
50	476	1.32	9.52	2 3/8	5 1/4	3 1/4	Med. Screw	Any	1000
60	585	1.29	9.71	2 5/8	5 1/2	3 7/16	Med. Screw	Any	1000
100	1010	1.24	10.13	3 3/4	7 7/8	5 3/16	Med. Sc. Sk.	Any	1000
Pear-shape Mazda C Lamps									
75	865	1.09	11.53	2 3/4	6 1/8	4 5/16	Med. Screw	Any	1000
100	1260	1.00	12.57	3 1/8	7 1/8	5 3/16	Med. Screw	Any	1000
150	2050	0.92	13.66	3 1/8	7 1/8	5 3/16	Med. Screw	Any	1000
200	2920	0.86	14.61	3 3/4	8 3/8	6	Med. Screw	Tip Down*	1000
300	4850	0.78	16.11	4 3/8	9 3/4	7	Mog. Screw	Tip Down*	1000
400	6150	0.82	15.32	5	10	7	Mog. Screw	Tip Down*	1000
500	8050	0.78	16.11	5	10	7	Mog. Screw	Tip Down*	1000
750	12800	0.74	16.98	6 1/2	13 3/8	9 1/2	Mog. Screw	Tip Down*	1000
1000	18000	0.70	17.95	6 1/2	13 3/8	9 1/2	Mog. Screw	Tip Down*	1000
Pear-shape Mazda C-2 Lamps									
75	600	1.58	8.0	2 3/4	6 1/8	4 5/16	Med. Screw	Any	700
100	870	1.44	8.7	3 1/8	7 1/8	5 3/16	Med. Screw	Any	700
150	1400	1.34	9.4	3 1/8	7 1/8	5 3/16	Med. Screw	Any	700
200	2000	1.25	10.1	3 3/4	8 3/8	6	Med. Screw	Tip Down*	700
300	3350	1.12	11.2	4 3/8	9 3/4	7	Mog. Screw	Tip Down*	700
500	5600	1.12	11.2	5	10	7	Mog. Screw	Tip Down*	700
Round-bulb Mazda B Lamps									
15	123	1.53	8.21	2 5/16	3 3/4	2 1/4	Med. Screw	Any	750
15	132	1.43	8.79	3 1/8	4 3/4	2 3/4	Med. Screw	Any	750
25	222	1.45	8.67	2 5/16	3 3/4	2 1/4	Med. Screw	Any	750
25	240	1.35	9.31	3 1/8	4 3/4	2 3/4	Med. Screw	Any	750
40	386	1.33	9.45	3 1/8	4 3/4	2 3/4	Med. Screw	Any	750
60	630	1.23	10.22	3 3/4	5 1/2	3 1/8	Med. Screw	Any	750
100	1100	1.18	10.65	4 3/8	7 1/4	4 1/2	Med. Sc. Sk.	Any	750

*Orders for Mazda C lamps should specifically state if lamps are for use in other than pendent position.

employ the larger units. Where the number of outlets which can be employed advantageously is not so definitely fixed, a greater choice in the selection of a size of lamp exists, and no difficulty should be experienced in selecting a size which will provide an intensity approximating that originally assumed as the desirable value. Here again, when a choice must be made, a higher intensity than that originally assumed should receive the preference over a lower one.

The chart below has been prepared to show at a glance the important factors entering into illumination design. It may be mentioned that the order of operations can readily be varied to suit the requirements of individual problems. For example, if it is desired to check the illumination intensity secured from a given system, the formula may be written in the form

$$\frac{\text{Coefficient of Utilization} \times \text{Number of Outlets} \times \text{Lumens per Outlet}}{\text{Area in Square Feet} \times \text{Depreciation Factor}} = \text{Foot-candles}$$

CHART OF IMPORTANT FACTORS IN ILLUMINATION DESIGN

Choice of System Page 422	Glare and Reflected Glare Shadow Illumination of Vertical Surfaces Efficiency Wall Brightness Available Units
Choice of Intensity Page 423	Nature of Work Advertising Value Table No. I, page 423
Depreciation Factor Page 424	Depreciation of Lamp in Service Depreciation of Equipment and Lamp Due to Collection of Dust
Coefficient of Utilization Page 424	Light Absorbed by Reflecting Equipment Light Absorbed by Ceiling and Walls Size of Room Table No. II, page 424
Location of Lamps Page 426	Relation of Spacing Distance to Hanging Height Constructional Features of Rooms or Building Table No. III, page 426
Mazda Lamps Page 427	Up-to-date Values of Lumen Output Color Quality of Light Table No. IV, page 428
Calculation of Lumens per Outlet Page 428	$\frac{\text{Foot-Candles} \times \text{Depreciation Factor} \times \text{Area in Sq. Ft.}}{\text{Coefficient of Utilization} \times \text{Number of Outlets}} = \text{Lumens per Outlet}$

Ornamental Utilitarian Street Lighting Units

By S. L. E. Rose and H. E. Butler

Illuminating Engineering Laboratory, General Electric Company

This article is really a companion to "Street Lighting with Modern Electric Illuminants," which appeared in the December 1917 issue of the General Electric Review, as it gives similar data on some new types of units. The former article discussed briefly the developments and advances in lamps and equipment, as well as the various factors entering into street lighting problems and contracts. As this information is not repeated below, the former article should be read in order to obtain the full value of this one.—Editor.

At the present time a large amount of residential, park, and boulevard lighting is done by means of ball-globe units of diffusing glass mounted on top of a post. These units give over 50 per cent of their total light in the upper hemisphere, and although their appearance is good they are very wasteful. A comparison of a ball-globe unit with one of the modern Novalux ornamental refractor units is given in Fig. 1. It can be seen from this that the new unit gives practically all of its light in the lower hemisphere with a characteristic distribution of candle-power which tends to give a maximum amount of light between units.

The ornamental Novalux refractor unit gives twice the foot-candle intensity on the street that the ball-globe unit gives, and will no doubt replace the ball-globe unit to a large extent for this class of lighting.

Since writing the article "Street Lighting with Modern Electric Illuminants" which appeared in the December 1917 issue of the General Electric Review, similar data have been obtained on some new designs of street-lighting fixtures made possible by the development of the Holophane prismatic dome refractor and stippled glass enclosing globes. Both of these developments have been adapted for use on pendent and orna-

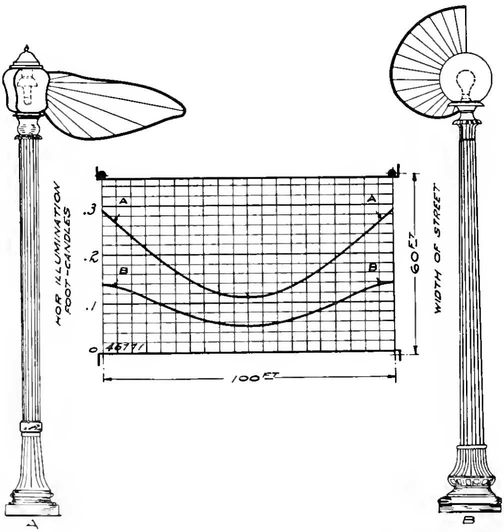


Fig. 1. Curves of Light Distribution and Intensity showing the Superiority of the Ornamental Novalux Refractor Unit over the Ball-globe Unit

Fig. 2-a. Pendent Type Novalux Unit with Stippled Globe and Dome Refractor

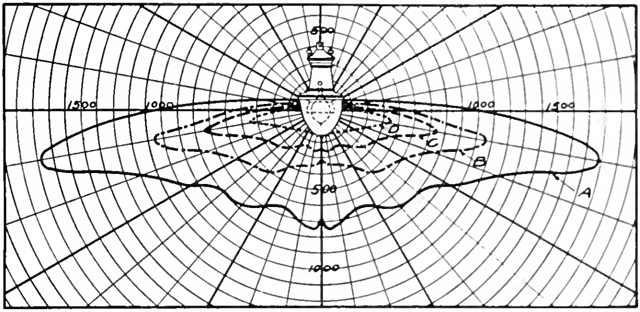


Fig. 2-b. Initial Distribution of Candle-power in a Vertical Plane of the Unit shown in Fig. 2-a

Curves A, B, C, and D correspond to the lamps named in Fig. 2-c

mental fixtures. These data should prove a valuable addition to the former article.

It is not practical to use a refractor inside a diffusing glass globe as the diffusing glass nullifies its effect. For this reason it was impossible to design an ornamental fixture using the refractor and concealing it by the use of diffusing glassware. Globes of stippled glass have a high transmission factor and have very little effect on the distribution of the light from the prismatic refractor. Therefore, with the development of globes of stippled

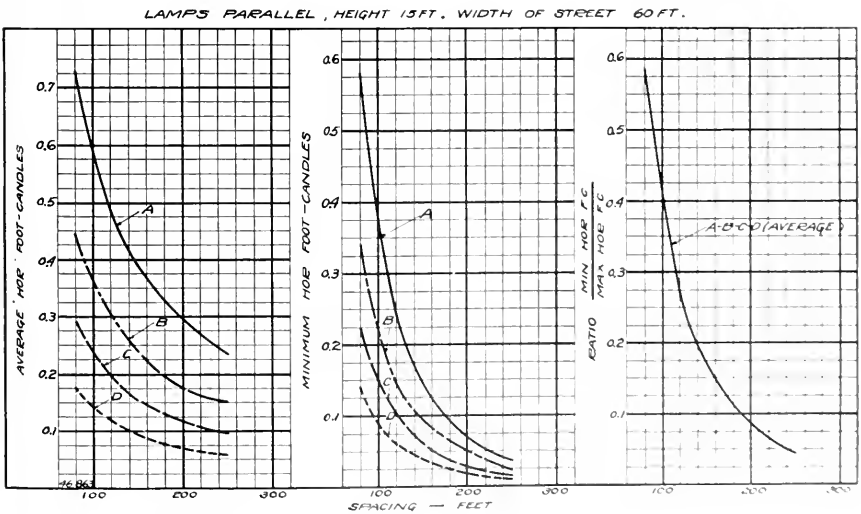


Fig. 2-c. Calculated Illumination Values on Street Surface along Center Line of Street

Lamps on one side of street only, on 4-ft. [illegible] Height 25 [illegible] Width [illegible]

A—1000 c-p., 20 [illegible] amp. Mazda Series Lamp, PS-40 B[illegible]
B—600 c-p., 20 [illegible] amp. Mazda Series Lamp, PS-[illegible] B[illegible]
C—400 c-p., 15 [illegible] amp. Mazda Series Lamp, PS-40 B[illegible]
D—250 c-p., 6.6 amp. Mazda Series Lamp, PS-35 B[illegible]

glass it was possible to design fixtures employing the refractor and concealing it inside the globe without materially changing its effect.

The pendent type fixture with stippled glass globe and dome refractor is shown in Fig. 2-a. Its characteristic distribution of candle-power is illustrated in Fig. 2-b; and the illumination on the street surface for various spacings are given in Fig. 2-c. In Fig. 2-a the globe is lowered to show the refractor.

The use of the stippled glass globe on the pendent unit with dome refractor makes a better appearing unit than when the refractor is used alone and also reduces the glare. This unit may be used instead of the one shown in Fig. 6* or wherever a refractor is needed with of upward light is useful in lighting the building facades or other surfaces.

The ornamental units shown in Figs. 3 and 4 are for use in residential districts, parks, boulevards, or other places where it is desirable to get all the light possible onto the street surface, for in most of these districts the upward light is wasted. Which unit to use will usually be indicated by the class of lighting district, or the appropriation available.

The illustrations in this article comprise a picture of the unit, the candle-power distribution curves, and the calculated illumination curves; the latter give the average and minimum foot-candles and the uniformity of

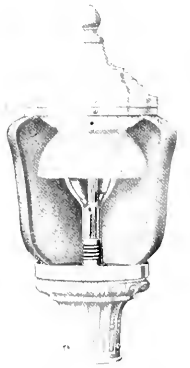


Fig. 3-a. Ornamental Novalux Unit, 3-section Stippled Glass Globe and Dome Refractor

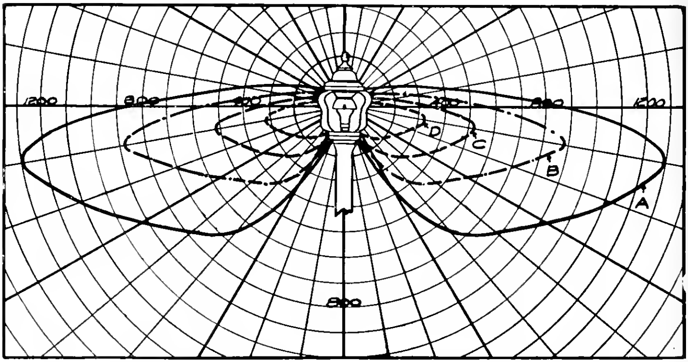


Fig. 3-b. Initial Distribution of Candle-power in a Vertical Plane of the Unit shown in Fig. 3-a

Curves A, B, C, and D correspond to the lamps named in Figs. 3-c and 3-d

the 250-, 400-, 600-, or 1000-candle-power Mazda series lamps.

Two designs of ornamental units with dome refractor may be employed, one using a three-section stippled glass globe, Fig. 3-a, and the other an eight-panel globe with stippled glass panels, Fig. 4-a. The candle-power distribution and calculated illumination values along the center line of the street for various spacings with lamps arranged parallel and staggered are shown in Figs. 3-b, 3-c, 3-d, 4-b, 4-c, and 4-d respectively.

The ornamental units shown in Figs. 7* and 8* are for whiteway lighting in business districts or other places where the large amount illumination for various size lamps and spacings. The uniformity factor is the ratio of minimum to maximum foot-candles.

From these curves, the following are some of the questions that may readily be answered:

With a given arrangement and spacing of units, what will be the average or minimum intensity of illumination on the street surface?

What spacing and arrangement of various units and equipment will give equal average or minimum illumination or equal uniformity?

What effect on the illumination and uniformity has staggered or parallel arrangement of units?

*In "Street Lighting with Modern Electric Illuminants," Dec. 1917.

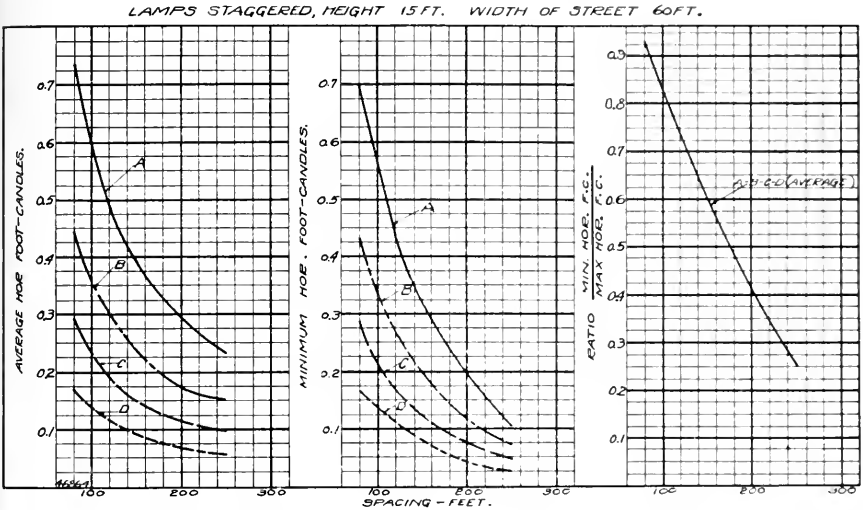


Fig. 3-c. Calculated Illumination Values on Street Surface along Center Line of Street

Lamps Staggered, Height 15 ft. Width of Street 60 ft.
A—1000 c-p., 20 amp. Mazda Series Lamp, PS-40 Bulb
B— 600 c-p., 20 amp. Mazda Series Lamp, PS-40 Bulb
C— 400 c-p., 15 amp. Mazda Series Lamp, PS-40 Bulb
D— 250 c-p., 6.6 amp. Mazda Series Lamp, PS-35 Bulb

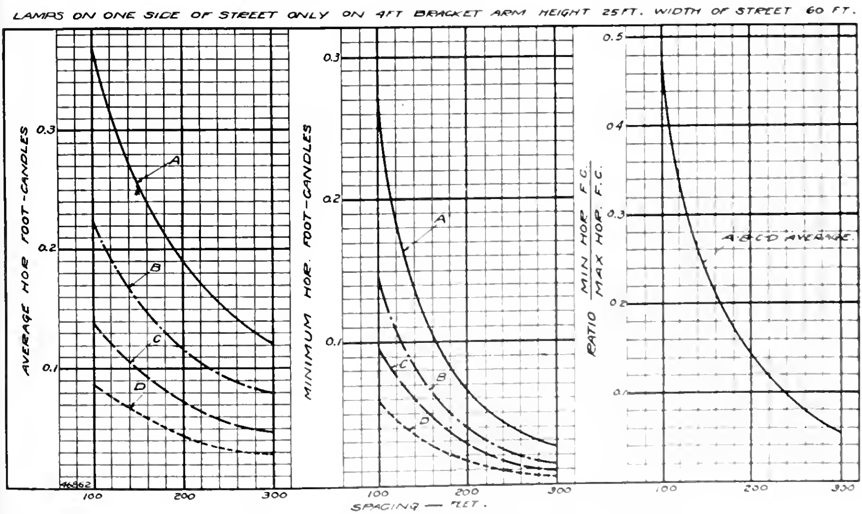


Fig. 3-d. Same as Fig. 3-c, except lamps are arranged parallel instead of staggered

If it is desired to use two or more units per pole, the values given on the curves and the wattage should be increased in the corresponding ratio.

Table I gives the data on Mazda 6.6- and 7.5-amp. series lamps.

TABLE I

DATA ON MAZDA SERIES LAMPS

Nominal Rated C-P.	Total Lumens	Watts	
		6.6 Amps.	7.5 Amps.
250	2500	155	147
400	4000	244	228
600	6000	368	344

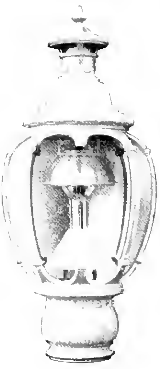


Fig. 4-a Ornamental Novalux Unit with 8-panel Stippled Glass Globe and Dome Refractor

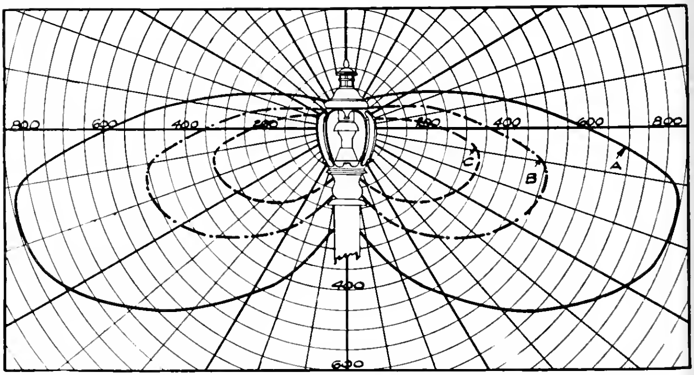


Fig. 4-b. Initial Distribution of Candle-power in a Vertical Plane of the Unit shown in Fig. 4-a

Curves A, B, and C correspond to the lamps named in Figs. 4-c and 4-d

Table II gives data on high-current Mazda lamps which are operated from auto-transformers having 6.6 or 7.5 amperes primary and 15 or 20 amperes secondary.

TABLE II

Nominal Rated C-P.	Total Lumens	Lamp Amperes	Watts at Auto-Transformer
400	4000	15	245
600	6000	20	330
1000	10000	20	544

Various classes of street lighting or districts will require different intensities of illumination. The important streets and districts usually are given preference over the unimportant streets.

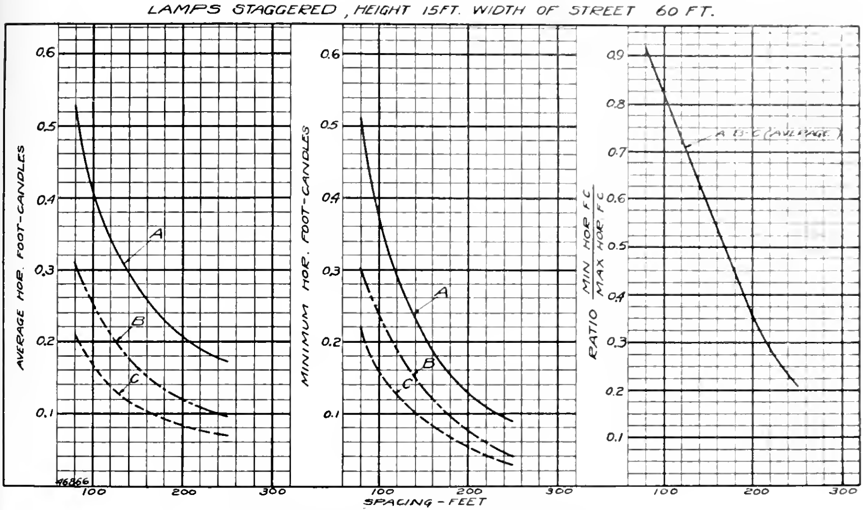
Table III indicates foot-candle intensities for various districts, but local conditions may make it necessary to change from the values given.

TABLE III

	Average Hor. Illum. Foot-candles
Principal streets in cities	0.25 to 1.0
Important side streets	0.10 to 0.25
Residence streets	0.01 to 0.05
Suburban roads	0.005 to 0.01

The color or reflecting power of pavement and building surfaces greatly influences the appearance of a street. Dirty and dark colored surfaces require a higher foot-candle intensity than light colored surfaces in order to appear equally well lighted.

The curves give initial values of candle-power and illumination, so that if it is necessary to guarantee these values a depreciation factor must be used. This will depend on local surroundings and maintenance. Obviously, if the units are installed where they are subjected to excessive dust and smoke, the candle-power and illumination will fall off more rapidly and to a greater extent than for those installed where very little dust and smoke are encountered. Also, if the units are cleaned frequently and systematically, the average results will be much better than if only infrequent attention and cleanings are given.



Fig, 4-c. Calculated Illumination Values on Street Surface along Center Line of Street

Lamps Staggered. Height 15 ft. Width of Street 60 ft.
A—1000 c-p., 20 amp. Mazda Series Lamp, PS-40 Bulb
B— 600 c-p., 20 amp. Mazda Series Lamp, PS-40 Bulb
C— 400 c-p., 15 amp. Mazda Series Lamp, PS-40 Bulb

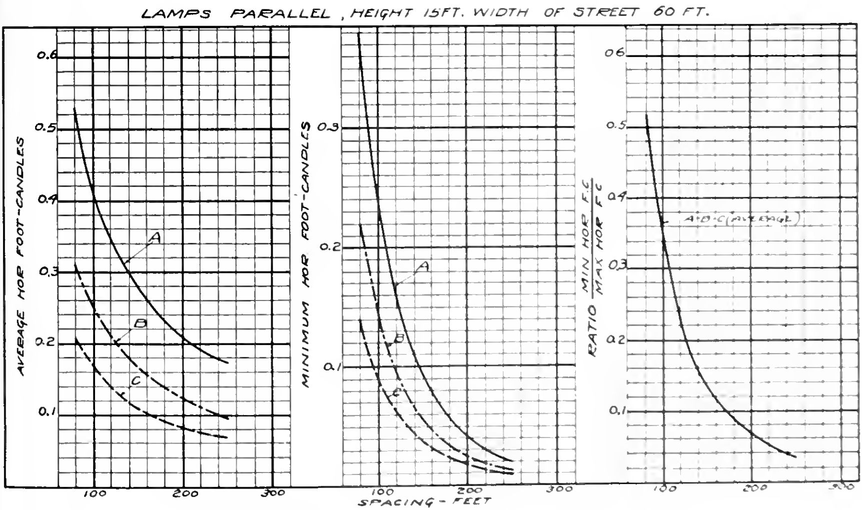


Fig. 4-d. Same as Fig. 4-c, except lamps are arranged parallel instead of staggered

Large Single-phase Starting Motors

By W. C. K. Altes

Induction Motor Department, General Electric Company

The following article is the last of a series of articles by Mr. Altes on Alternating-current Motors. The theory and application of various types of alternating-current commutator motors have been covered as follows: "Single-phase, alternating-current motors," July, 1916, page 579; "Theory of the single-phase, alternating-current motor," Dec., 1916, page 1072, Jan., 1917, page 86; "Brush-shifting polyphase series motors," Feb., 1916, page 115, March, 1916, page 199; and "The polyphase shunt motor," May, 1918, page 317. In the present article the author shows how the problem of building a large single-phase starting motor was solved economically by using a series motor having two separate circuits and two brush studs per pole, instead of the usual arrangement. He describes how this particular machine has been applied and how a machine of this type could be used as a direct-current exciter after the set which it starts has been brought up to speed. He finally mentions the considerations of design which make the repulsion motor suitable for a small starting motor; the two-circuit series motor most suitable for medium sizes, and the plain one-circuit series motor best for the largest sizes.—Editor.

Last year there was completed a frequency changer set consisting of a 25-cycle, 10,000-kv-a., single-phase synchronous motor and a 60-cycle, three-phase synchronous generator.

In order to be able to start this frequency changer set from the single-phase supply, in case of a break-down of the three-phase system, a single-phase, 25-cycle starting motor was built. Standard induction motor parts were used wherever possible, to reduce the cost of special development. The guaranteed starting torque of the motor is 30,000 ft.-lb., and the full speed of the set is 300 r.p.m.

At first, it was attempted to design this motor as a repulsion motor. This type of design limits the number of poles as the commutation of the repulsion motor becomes very bad above synchronous speed. The result was that the output per pole would have to be so great that the repulsion motor design was abandoned. The logical solution seemed to be the application of a series motor.

With the plain series motor having a multiple drum armature, the maximum number of brush studs is one per pole. In order to avoid sparking at starting, the voltage between commutator bars must be kept low and the brushes must be made narrow so as not to short-circuit too many bars. Keeping the volts per bar low results in a low-voltage machine, and the brush area required is the same as that of a direct-current low-voltage machine of the same capacity. On account of the narrow brushes of the alternating-current motor, however, a less number of square inches of brush surface per inch axial length is obtained than on the direct-current machine, and the commutator of an alternating-current motor would be even longer than that of the direct-current machine of the same capacity. To utilize the commutator more efficiently and to avoid the very long narrow and therefore expensive design, toward which these considerations tend, it is necessary to use as many brush studs as possible. This would require 40 poles on the design under consideration. Such an arrangement would give too small an

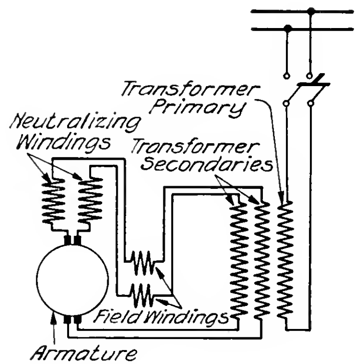


Fig. 1. Diagram of a Two-circuit Series Motor connected to a transformer having two secondary coils.

output per pole to obtain an economical motor design. A small output per pole would be satisfactory only with a small air gap; and, for mechanical reasons, it was necessary to figure on a liberal air gap for this large motor. Thus, an economical commutator design led to an uneconomical motor design. This difficulty was overcome by designing the motor as a two-circuit series motor with 20 poles.

The connections of a two-pole, two-circuit series motor are shown in Fig. 1. Instead of using one neutralizing and one field winding and one wide brush per pole, as on direct-current motors, two narrow brushes are used per pole, each brush being connected to an individual neutralizing winding and field winding. By building the secondary of the transformer with two circuits, two entirely separate motor circuits are obtained. If no such transformer is available, it would be necessary either to connect the lines to the middle of reactances which connect brushes of the same polarity as shown in Fig. 2, or to divide the neutralizing winding into four sections as shown in Fig. 3, and depend upon the impedance of the neutralizing winding to prevent the flow of current between adjacent brushes.

The advantage of the two-circuit type of motor over the straight series motor becomes apparent when it is realized that an ordinary 20-pole series motor developing the required torque would have required a commutator of twice the size, for the brushes would have to be placed on the commutator in a single row instead of being arranged in two rows.

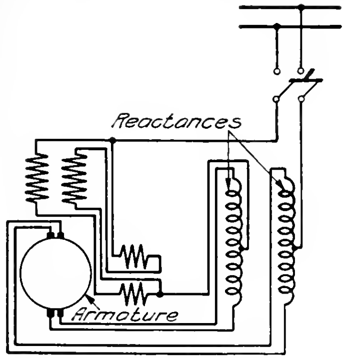


Fig. 2. Diagram of a Two-circuit Series Motor using reactance to limit the flow of current between adjacent brushes

As it was desired to use standard induction motor punchings and to adhere to induction motor winding practice, it was found undesirable to make specially large slots for the field coils. Consequently, an attempt was made to use a single stator winding, a part of which would act as the field and another part as the neutralizing winding. To get the proper compensation of the armature reaction it was found that the best arrangement would be to use a full-pitch armature winding and to make the angle between the neutral and the field coils somewhat greater than the angle between adjacent brushes, which could be done by leaving one slot per pole empty.

In the stator two kinds of coils were used, one having (a) and the other (b) turns per coil.

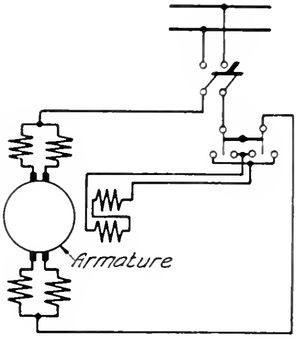


Fig. 3. Diagram of a Two-circuit Series Motor having four neutralizing coils

In this way, it was possible to obtain ($a+b$) field turns per pole and a distribution of the compensating winding leading to a complete compensation of the armature reaction over an angle corresponding to four stator slots for every two poles and an over-compensation

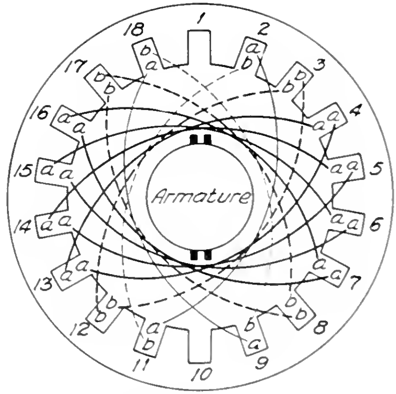


Fig. 4. Diagram showing Arrangement of Neutralizing and Field Windings in the Stator

over the remaining angle. The arrangement of the number of conductors in the slots for two poles of the machine is shown in Fig. 4. Fig. 5 is a diagram of the magnetomotive forces of the armature winding, the field winding, and the neutralizing winding.

As the motor was to run for a few minutes only, it was considered unnecessary to [illegible]

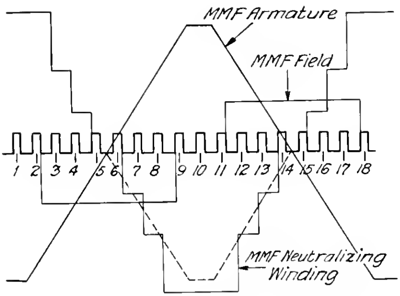


Fig. 5. Diagram showing Relative Magnitude and Location of Magnetomotive Forces of Neutralizing and Field Armature Windings

means for improving the running commutation. This could have been done either by providing a commutating pole winding, or by running the motor as a series repulsion motor instead of a straight series motor. As far as the current commutation is concerned, the two-circuit series motor is superior to the single-circuit series motor, due to the fact

The primary of the transformer is directly connected across the 11,000-volt lines. At starting, the reactance drop of the transformer limits the secondary voltage of the transformer to 150 volts. At full speed (300 r.p.m.) the secondary voltage of the transformer is equal to 232 and the motor develops approximately 700 h.p. This large internal regulation of the transformer is beneficial for bringing the set up to speed in a short time, as the increase in the secondary line voltage results in an increased output of the motor at high speed.

At first it was planned to keep the secondary of the transformer permanently connected to the motor and to start the motor by throwing the primary of the transformer across the line. When following this method in testing the motor it was noticed that the starting torque increased very suddenly, and it was feared that too severe a strain would be put on the clutch coupling. The connection was, therefore, changed to that shown in Fig. 8. When the primary of the transformer is connected across the line, the motor is connected to the secondary over a high resistance and thus the current is limited.

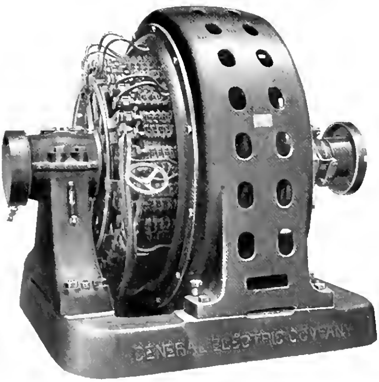


Fig. 6

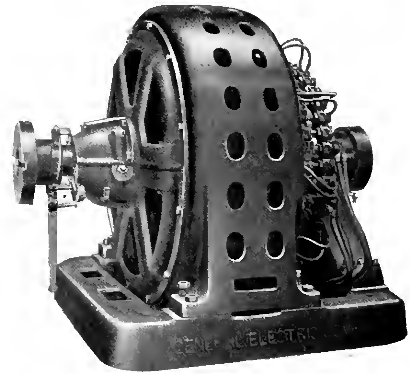


Fig. 7

Two Views of a Single-phase, 25-cycle, 20-pole, 700-h.p., 300 r.p.m. Series Starting Motor having 30,000 ft-lb. starting torque

that the current in the coils short-circuited by the brushes is not reversed but is changed from full value to zero and then from zero to full value in the opposite direction.

Figs. 6 and 7 show the assembled motor complete with the clutch coupling for disconnecting the motor after it has started the motor-generator set.

An instant after closing the primary line switch the contactors go in and short-circuit these current-limiting resistances. In this way the torque is applied in two steps instead of in one, and the strain on the coupling is considerably reduced.

By common connecting the adjacent brushes the motor can be run from a single direct-current line. This was done in test loading the motor to 825 h.p. output at 300 r.p.m. which was the largest output the belt could safely transmit. The commutation as a direct-current motor was sparkless, which indicated that the windings had been properly proportioned.

The two-circuit series motor is particularly suitable for intermittent duty. On motors which run for a considerable length of time and on railway motors which have a high brush tension it is impossible to use such a large number of studs around the commutator on account of heating. In the latter service the application of the two-circuit series motor can still be advantageous if brushes are omitted on one part of the commutator to make the holders accessible through two removable covers. By using the two-circuit series motor the same number of studs can be used as on the straight series motor, putting them all in front of the hand-holes.

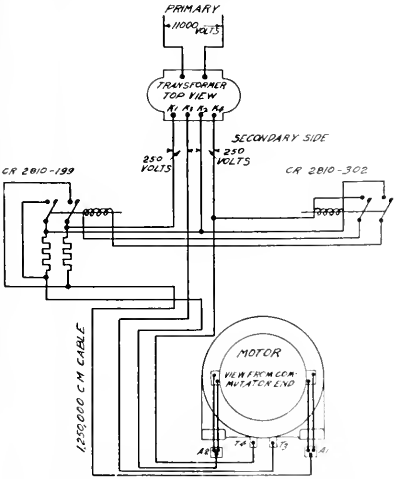


Fig. 8. Diagram of Connections of a Series Motor showing arrangement of current-limiting resistance

Fig. 9 shows the arrangement of the holders for an eight-pole, two-circuit series motor on which eight studs have been omitted. In this case it is necessary to equalize all the commutator bars, unless a series armature is used.

The starting motor can be designed in such a manner that it may be used as a direct-current exciter for the synchronous machine after the set is up to speed. The field coils should have a large number of turns in order to make it possible to connect them across the neutralizing and armature winding when operating as exciter. In the starting connection the field winding can be connected to the secondary of a series transformer so as to reduce the high alternating current at

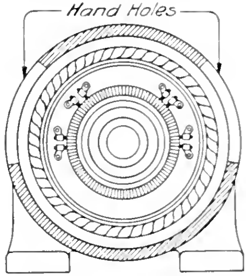


Fig. 9. Mechanical Arrangement of Brush Studs on a two-circuit series motor

starting to a value suitable for the field winding. The connections for an arrangement of this kind are illustrated in Fig. 10.

It may be of interest to investigate how much starting torque can be obtained with the different connections. Assume that a 25-cycle, 1500-r.p.m. motor is to be built. If the peripheral speed of the commutator is to be limited to 4000 feet per minute, a commutator of 10 inches diameter can be used. A repulsion motor of this speed can be built with two poles and six brush-studs spaced 30-30-120-30-30-120, etc. degrees. Using 144 commutator bars with five volts per bar, and six brushes per stud each carrying 60 amperes at start, 225 synchronous kilovolt-amperes starting torque or 1055 foot-pounds can be developed. This capacity is obtained by using 60,500 ampere conductors per pole, which leads to a very small ratio between field turns and armature turns, unless the motor is built with an exceedingly large air-gap.

Building a two-circuit series motor with four poles, eight studs spaced 11.25-78.75-11.25, etc. degrees, and six brushes per stud, results in [illegible] synchronous kilovolt-amperes or 1510 foot-pounds starting torque, and 22,500 ampere conductors per pole.

Building a single-circuit series motor with eight poles, eight equally spaced brushes, and six brushes per stud, results in 82[illegible] synchronous kilovolt-amperes or 1535 foot-pounds starting torque and 6500 ampere conductors per pole. In this machine, the ampere conductors per pole are relatively low and can readily be doubled by using 12 instead of 6 brushes per stud, which gives 3070 foot-pounds starting torque. By going to higher peripheral speed on the commutator and increasing the number of poles in the same ratio as the diameter of the commutator, the torque which increases as the square of the peripheral speed can be raised considerably. Thus, by going to a peripheral speed of 6000 feet per minute (requiring a 15-inch diameter commutator and twelve poles) there results $\left(\frac{6000}{4000}\right)^2 \times 3070 = 6900$ ft.-lb. starting torque with 13,000 ampere conductors per pole. In case it is desired to build a 300-r.p.m. motor, $\frac{1500}{300} \times 12 = 60$ poles must be used which will result in a starting-torque of $\left(\frac{1500}{300}\right)^2 \times 6900 =$ 172,500 ft.-lb. This shows that it is possible to build single-phase starting motors for even very large frequency changer sets. For the largest sets, the single-circuit series starting motor should be used; for the medium sets, the two-circuit series motor; and for the smaller sets, the repulsion motor. The repulsion motor has the advantage that it often can be built for operation without transformers.

The design of the 30,000 foot-pound starting motor was made in consultation with Mr. E. F. W. Alexanderson whose advice was of great value to the writer.

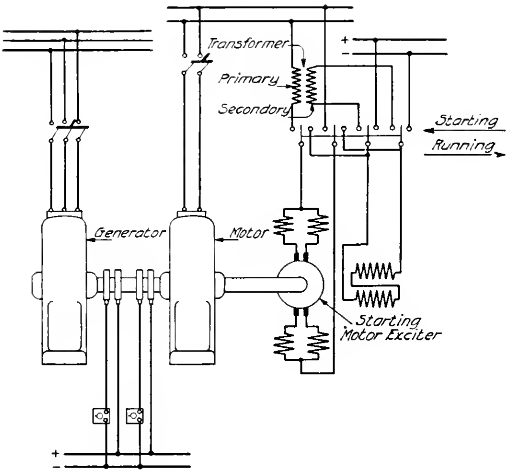


Fig. 10. Diagram of Connections of a Series Motor showing switch to make the machine function as a direct-current exciter when up to speed

The Central Station and Illumination

By H. E. Mahan

Illuminating Engineering Laboratory, General Electric Company

In this article the subject of illumination is treated from the standpoint of central-station companies, and the broader view of rendering expert service to the customer, rather than the too prevalent method of indiscriminately loading up a customer with lamps, is emphasized. The principal considerations which it is necessary to bear in mind in order to carry out this policy are mentioned, and the value of co-operation between the lighting companies and the manufacturers is pointed out. The several general systems of lighting are discussed, and a word of caution is included regarding the use of projection apparatus. These are all matters of great moment to the central-station company and undoubtedly will be more fully recognized in the future than they have been in the past, with the result that the utilities will strengthen one of their greatest assets, the good will of the public.—Editor.

There is a tendency among the more progressive central stations to sell illumination to their customers, rather than lighting fixtures and power. This policy is largely an outgrowth of the introduction of the high efficiency incandescent lamp which, when placed upon the market, caused many central station managers no little concern. It was felt that with the higher efficiency lamps customers would use less power to obtain equal illumination, which view overlooked the fact that cheaper light would encourage the use of more light and introduce electricity into places where it was not afforded before. The central station manager is continuing to view the illumination problem from this broader viewpoint, realizing that one of the strongest assets a utility can possess is the good will of the public.

The man to whose lot it falls to carry this message of co-operation and service to the public is the new business manager. He is a very busy man and can devote only a fractional part of his time to keeping abreast of illumination progress. The subject of lighting is developing so rapidly and its relation is so vital to the central station that many of them have established departments of illumination in charge of illuminating engineers, whose duty it is to provide and encourage proper lighting. The larger electrical manufacturing companies are also maintaining at a cost of thousands of dollars a year, laboratories for research and development work and for the study of the application of light. Thus we find the manufacturers prepared to serve the central station and the central station in turn anxious to assist the customer, both realizing the value of co-operation and of satisfying the actual consumer.

The laws governing correct illumination are few and simple, and their fulfillment reacts to the advantage of both the central station and the consumer. To the former it means that the lighting load is as great as it should be, and to the latter it insures proper visual conditions. Selling illumination merely means that the central station assumes the responsibility of providing its customers with a system of lighting adequate for their needs and in accordance with modern practice; the central station in return receives the good will and loyalty of the customer.

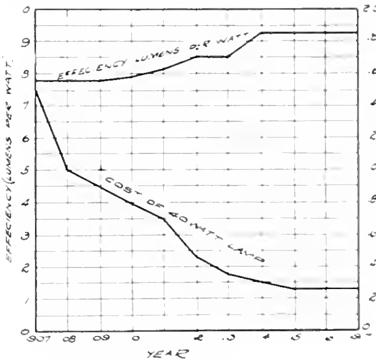


Fig. 1 Curves of Efficiency and Lamp Cost

The incandescent lamp may be considered the raw material of a lighting system, as it requires to be equipped with reflectors, glassware, etc., to reduce the intrinsic brightness, to diffuse the light, to give it proper direction, and to provide color modification. It is therefore highly desirable that the lamp itself be as efficient as possible, so that the ultimate efficiency, after properly modifying the raw light, will be high relative to other forms of illumination. Electric lighting stands unique in being one of the few universally used commodities which has decreased in cost to the consumer during the past decade. This may be attributed to both the central station and to the manufacturer. To the former we owe the decrease in the cost of electric power, and to the latter the increased efficiency and the lowered cost of lamps. The curves in Fig. 1 indicate the decrease in selling price of the 40-watt Mazda lamp (representing the most popular size) for the past ten years and also the increase in efficiency during this period. When we consider these figures in connection with the decrease in the price of electric power during the past ten years, we find that today approximately 80 per cent more light is obtainable for the same cost than could be had ten years ago. If we compare the Mazda lamp of today with the carbon filament lamp of 10 years ago we find that this percentage is increased to about 400 per cent.

The indirect system employs an opaque bowl beneath the lamp and reflects the light toward the ceiling, from which it is reflected and diffused about the room. It is obvious that the efficiency of this system depends largely upon the color and character of the ceiling finish and that the system is entirely unsuited to rooms with a dark finish. This system has the maximum of diffusion and the minimum of glare, but the flatness and distortion resulting from so highly a diffused light condemn it for many places.

The semi-indirect system is a combination of the direct and indirect systems, and

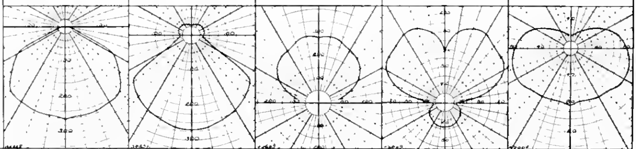
	DIRECT LIGHTING		INDIRECT LIGHTING	SEMI-INDIRECT LIGHTING	DIFFUSED LIGHTING
	OPAQUE	TRANSLUCENT			
DISTRIBUTION CURVES					
LUMENS BARE 100W LAMP	1260	1260	1260	1260	1260
LUMENS DELIVERED BY FIXTURE	805	1031	1036	1052	847
UPWARD LUMENS	0	227	1036	806	328
DOWNWARD LUMENS	805	804	0	246	519
RELATIVE WATTAGE REQUIRED FOR EQUAL HORIZONTAL ILLUMINATION (APPROX)	1.14	1	1.51	1.29	1.31

Fig. 2. Characteristics of Lighting Systems

Artificial lighting may be classified into four systems which are known as direct, indirect, semi-indirect, and diffusing. The characteristic light distribution of these several systems is indicated by Fig. 2, and they may be described as follows:

The direct lighting system involves the use of a lamp and reflector assembled to deliver the direct rays of the lamp toward the working plane. It is therefore the most efficient form of lighting in terms of light flux reaching the useful plane per unit of power consumed. It has the disadvantage, however, of distributing the light from a small source, and therefore it tends to create sharp shadows, although a large number of units and the use of translucent shades tend to minimize this. The glare tendency is also a maximum in this type of unit and it is therefore gradually losing ground to the other systems which afford greater eye protection.

assumes a division of the light between the upper and lower hemispheres. This gives a direct component of light from the unit and a highly diffused component from the ceiling. Such a system is the nearest approach to natural lighting conditions, where we get the direct rays from the sun and diffused light from the clouds, and is rapidly attaining popularity.

The diffusing system might be considered a combination of the direct and semi-indirect systems and usually takes the form of enclosing the lamp in a diffusing glass envelope of an appropriate design. The system has many attractive features and when installed with proper regard to eye protection and ornamental design it is extremely satisfactory.

The distribution of light from these various types of units is indicated in Fig. 2, together with other essential data. These curves represent the distribution of light in a perpendicular plane through the axis of the lighting unit so that all the light above the horizontal will go to the ceiling and all light delivered below the horizontal will be in the direction of the floor. The relative proportion of light flux delivered in the upper and lower hemispheres for typical units representing the several systems is shown in this chart, as is also the approximate relative wattage required to give an equal intensity of illumination on the working plane.

The essential considerations in planning lighting systems are those of glare, diffusion, efficiency, intensity of illumination, quality or color of light, and the appearance of the lighting unit.

Glare

In considering glare, we must remember that the eye sees objects by light reflected from the object and not by light directed from the light source to the eye. Therefore, we should endeavor to distribute the light so that it will fall on the objects to be seen and not on the eye. Glare is responsible for the failure of many lighting systems, and aside from the inconvenience it causes in seeing it has an injurious effect on the tissues of the eye.*

Glare exists when a light source of relatively high intrinsic brightness is present in the line of vision, and it operates to reduce the effectiveness of a lighting system in two ways. First, it is tiring and painful to the eyes, and in many instances harmful, as all of us can testify from experience in being compelled to view a bright light source. Secondly, the eye in closing up to exclude this bright light is handicapped in seeing relatively darker surroundings. An extreme example of this condition exists when we try to see beyond an approaching automobile having bright headlights.

Secondary glare has the same discomforting effect as glare from a light source and results from images of the light source being reflected from glossy surfaces, such as calendered paper, polished furniture, etc. Consideration to such details as this frequently enables the central station solicitor to make suggestions to eliminate the objectionable features from a system which is otherwise satisfactory. For example, a furniture store where highly polished wood is on display should have a form of indirect lighting in order to minimize this specular reflection or glare, while a jewelry store where gems and cut glass are on display might have direct lighting with shaded clear lamps to show the ware to best advantage. An otherwise successfully lighted store window is sometimes spoiled by the specular reflection of the light sources in a mirror or the highly polished woodwork forming the background of the window. Glare should be avoided in any form in a successful lighting system, and the observing central station representative will discover it to be responsible for many complaints against his company by customers whose lighting is unsatisfactory but who do not know what the trouble is.

* See "Eye and Illumination," G. E. REVIEW, April, 1915

Diffusion

We see objects by means of light and shade. In an extremely diffused light, objects appear shapeless and monotonous; analogous to the conditions on a cloudy day. In the case of a strongly directional light, dark and long shadows occur and unsatisfactory and disconcerting vision results. It is necessary, therefore, in order to have the lighting approximate natural conditions, to provide both diffused and directional light similar to the sunshiny day where we have direct light from the sun and diffused light from the clouds. The degree to which semi-indirect and diffused lighting systems fulfill these conditions has brought these systems very much in favor.

Efficiency

The true efficiency of a lighting system in so far as it is intended to indicate the success or satisfactoriness of a system cannot be expressed in physical units as in the case of an electric motor or generator. The real measure of a lighting system involves physiological, psychological, and artistic considerations, none of which may be expressed numerically. We can determine the lumens delivered by the bare lamp and compare this with the lumens delivered by the fixture, and we may go a step further and compare this latter figure with the lumens delivered on the working plane; but even if these figures indicate an efficient use of light, there remains the other factors of glare, diffusion, intensity, color, and appearance, any one of which may be inadequately taken care of and thus condemn the whole. Efficiency then should rank as a secondary factor in designing lighting systems, the aim of the designer being to secure a system which fulfills all the other requirements consistent with good economy.

Intensity of Illumination

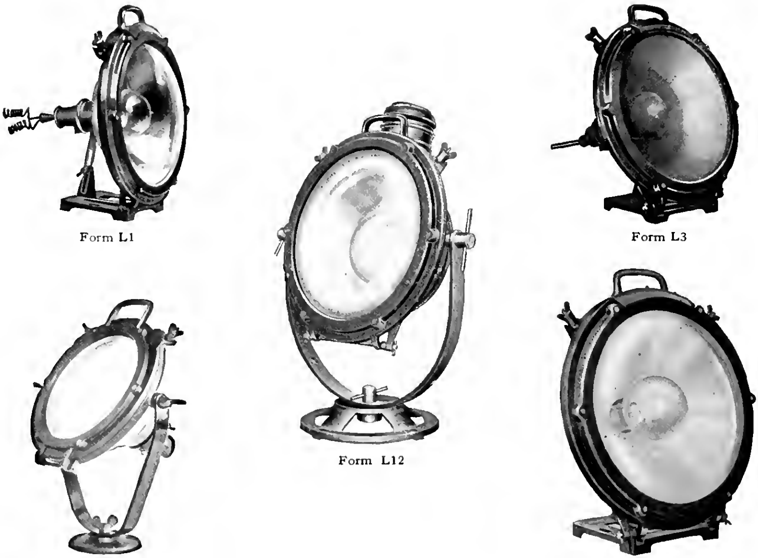
The intensity of illumination recommended should be determined after a careful study of the requirements to be fulfilled. A machine shop where fine work is carried on obviously requires more light than a space devoted to the storage of material, and again a textile mill working on white material does not require the light that a mill working on dark colored materials requires. The general practice for different classes of work has been determined from experience and numerous tables compiled by various authorities are available for reference. The central station company should be equipped to test the illumination on a customer's premises for check purposes and to accumulate data on satisfactory equipments for future reference. A number of practical portable photometers are on the market which will be found to be a very useful means of acquiring very valuable data to serve as a guide to future practice.*

* See "Measurement of Illumination," G. E. Review, May, 1913.

Color

In considering color, the thought necessary to keep in mind is that the color of an object results from the light it reflects to the eye and is not an inherent property of the object. The light reflected to the eye in turn depends upon the incident light. The standard by which the color of an object is judged is daylight. Therefore, when the daylight appearance of an object is important to know, it is necessary to provide artificial light approximating daylight in quality. This is extremely necessary in such places as dry goods stores, textile mills, photograph studios, etc., etc., and should receive careful consideration by the central station company.

It is entirely feasible to provide an artificial light approximating daylight in its spectral composition, but because of the relative inefficiency of such a system it is usually not provided over an entire plant or store, but only where needed such as over an inspection table, in a separate booth, etc. A number of the more progressive department stores, however, find it advantageous to provide light



Form L1

Form L3

Form L12

Form L11

Form L1 Medium Angle

Fig. 3. Floodlighting Projectors

corrected for daylight quality throughout their buildings. Equipment is available which permits of varying degrees of color correction, and hence varying degrees of efficiency, so that a satisfactory compromise may be reached between efficiency and color exactness which will meet the requirements of any situation. The Mazda C-2 lamp, which consists of the regular Mazda filament enclosed in a blue glass bulb for color correction, is becoming very popular for general lighting requiring approximate daylight quality.

feasible to have a true artistic design without violating the tenets of good lighting practice, and the central station company will find it advantageous to encourage the use of fixtures designed with particular reference to architectural and decorative considerations, and should freely lend its services to this end.

Floodlighting

The floodlighting of exteriors offers a broad field to the central station, but the enthusiasm which has been aroused by the floodlighting projector (Fig. 3) has caused it

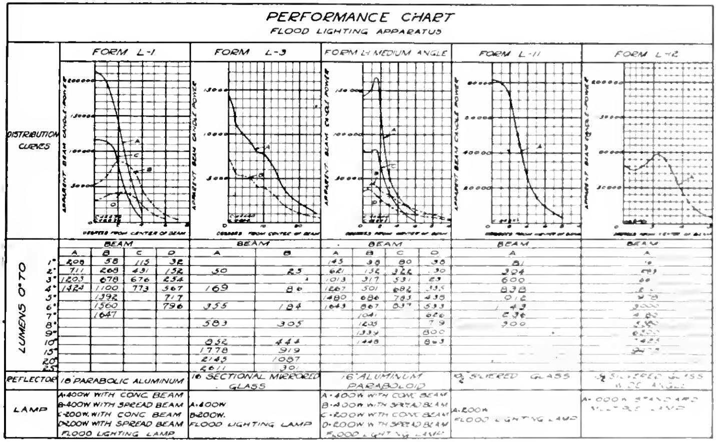


Fig. 4. Performance Chart

Light is also frequently filtered through color screens or colored glassware to obtain decorative and psychological effects. This is a field which offers wonderful opportunities to the central station company for increasing their load and at the same time giving customers distinctive and attractive lighting equipments. Stores, restaurants, homes, etc. offer exceptional opportunities for the central station illuminating engineer to exercise his imagination and obtain interesting effects, build up the station load, and make friends for his company.

Appearance

The appearance of a lighting unit is frequently the determining factor in an installation, particularly in stores, homes, and various types of monumental buildings. It is entirely

to be used in places where it is entirely unsuited. The function of projection apparatus is to deliver light at a relatively great distance, and to accomplish this a sacrifice in efficiency must be made; therefore the least concentrated beam that will successfully fulfill the requirements of any problem should be adopted. It is a very uneconomical form of lighting unit to employ for the interior lighting of shops and factories, and the distribution of light is also unsuited for general lighting of interiors as the light is too strongly directional and causes sharp shadows. The proper field of application for the so-called floodlighting projector is in the illumination of buildings, monuments, signs, etc., etc., where the concentration of the beam enables it to be projected relatively great distances and be made effective, in which case the utilization efficiency compensates for the sacrifice in the initial efficiency of the apparatus.

Great care should be exercised in planning a floodlighting installation if satisfactory results are to be obtained. An attempt should be made to approximate daylight conditions in order that the architectural details may be preserved in their proper form. This may be accomplished by delivering a strong component from one direction

FORMULA FOR DETERMINING NUMBER OF PROJECTORS $N = \frac{A \times E}{L}$

A = Area of building facade
E = Foot-candles required
L = Total lumens delivered by one projector
N = Number of projectors

See also Fig. 6 for areas of beams for projectors at varying distances.

In using the above data, allowance should be made for a reasonable overlapping of beams to eliminate striations.

INTENSITIES FOR FLOODLIGHTING

Building Surfaces	Character of Surroundings: White Way	Residences	Parks
Dark colored buildings, i.e., surfaces of red brick, clinker brick, brown stone, etc.	20 F.C.	15 F.C.	10 F.C.
Medium colored buildings, i.e., surfaces of concrete, granite, etc.	15 F.C.	10 F.C.	5 F.C.
Light colored buildings, i.e., surfaces of glazed terra cotta, marble, etc.	10 F.C.	5 F.C.	3 F.C.

LUMENS

Lamp	Type of Projector: Form L-1 S	Form L-1 C	Form L-3	L-1 Medium Angle S	L-1 Medium Angle C	Form L-11	Form L-12
200 watt (floodlighting)	796	773	1301	837	863	1300	
400 watt (floodlighting)	1647	1424	2611	1448	1643		
1000 watt (multiple 115 volts)							9475
1000 watt (multiple 220 volts)							9200

S—Spread beam. C—Concentrated beam.

Fig. 5. Tables of Intensities and Lumens for Floodlighting

and relieving these shadows by a less intense beam from the opposite direction. Colored light may also be used to advantage for relief lighting. The light should, where possible, come from above the object to be lighted in order to simulate sunlight direction.

The chart in Fig. 4 shows the performance of typical forms of floodlighting equipment. It will be noted that the width of beam varies with the several types in order that a suitable distribution may be obtained for various classes of service. From this chart may also be obtained the total lumens delivered by the unit to facilitate planning installations for specific intensities of illumination. The intensity of illumination depends, of course, upon the character of the building surface and the surroundings of the building. Floodlighting is a matter of contrast, and in order that a building may be emphasized by light it is necessary that it be relatively brighter than its neighbors. The chart in Fig. 5 indicates the intensities of illumination usually required for the successful floodlighting of various surfaces under various conditions of surroundings.

The chart in Fig. 6 shows the relation between distance, angle of incidence, and area of beam for the several types of projectors. It is desirable to have each flood lamp cover as large an area of the building as possible to provide for overlapping of the beams and thus minimize the effect of an outage and eliminate extreme variations in intensity.

Conclusion

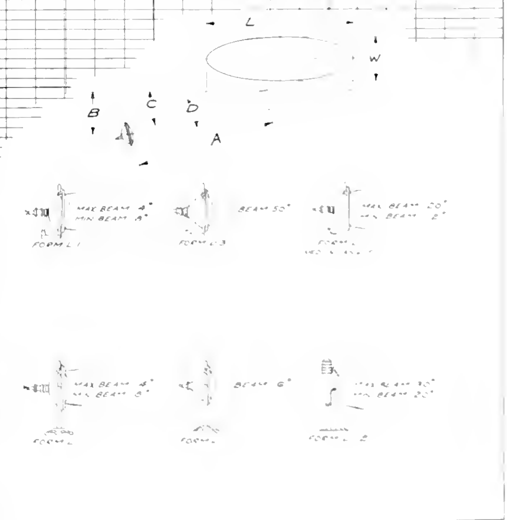
The central station has been inclined in the past to regard lighting as of minor importance, devoting its activities to increasing the power load. The fallacy of this policy is becoming evident and the manager of today is convinced that the extent of his lighting load depends entirely upon the efforts and ingenuity of his sales organization.

The problem as it confronts the central station manager appears simple, and requires only that he see that his solicitors and depart-

G.E. FLOOD LIGHTING PROJECTORS
AXES & AREAS OF BEAMS FOR GIVEN DISTANCES

A	B	C	FORM L-1 D=8° W	L	AREA	FORM L-1 D=14° W	L	AREA	FORM L-3 D=50° W	L	AREA
25 FT.	43	10	3.5	24	66	6.1	69	331	23		
	86	20	″	11	29	″	20	98	″		
	125	30	″	7	19	″	13	62	″	134	2452
	161	40	″	5.5	15	″	10	47	″	53	362
	192	50	″	4.6	13	″	8	39	″	36	630
	217	60	″	4	11	″	7.2	35	″	29	530
	235	70	″	3.7	10	″	6.5	32	″	26	468
	246	80	″	3.6	9.7	″	6.2	30	″	24	436
	25	90	″	3.5	9.5	″	6.1	29.5	″	23	426
50 FT.	8.7	10	7	48	262	12.3	137	1322	47		
	17	20	″	21	116	″	41	331	″		
	25	30	″	14	78	″	26	248	″	268	3810
	32	40	″	11	61	″	20	186	″	105	3855
	38	50	″	9	52	″	16	156	″	72	2630
	43	60	″	8.2	45	″	14	138	″	58	2120
	47	70	″	7.4	41	″	13	126	″	51	1870
	49	80	″	7.1	39	″	12.5	120	″	48	1742
	50	90	″	7	38	″	12.3	118	″	47	1706
75 FT.	13	10	10.5	72	591	18.4	206	2977	70		
	26	20	″	32	263	″	61	880	″		
	38	30	″	21	175	″	39	558	″	403	22068
	48	40	″	17	135	″	29	424	″	158	863
	57	50	″	14	113	″	24	351	″	108	5920
	65	60	″	12	101	″	22	311	″	87	4770
	70	70	″	11	92	″	20	284	″	77	4210
	74	80	″	10.6	88	″	18.7	270	″	72	3922
	75	90	″	10.5	86	″	18.4	266	″	70	3837
100 FT.	17	10	14	96	1050	24.6	274	5280	93		
	34	20	″	43	467	″	81	1561	″		
	50	30	″	28	312	″	52	397	″	536	39250
	64	40	″	22	242	″	39	752	″	210	15980
	77	50	″	18	200	″	32	624	″	144	10525
	87	60	″	16	179	″	29	557	″	116	8475
	94	70	″	15	164	″	26	504	″	102	7485
	99	80	″	14.2	156	″	25	480	″	96	6975
	100	90	″	14	154	″	24.6	474	″	93	6820
125 FT.	22	10	17.5	120	1640	30.7	344	8100			
	43	20	″	53	724	″	102	2445			
	63	30	″	35	467	″	64	1550			
	80	40	″	27	377	″	49	1178			
	96	50	″	23	315	″	41	976			
	108	60	″	20	279	″	36	866			
	118	70	″	19	255	″	33	788			
	123	80	″	18	244	″	31	751			
	125	90	″	17.5	240	″	30.7	740			
150 FT.	26	10	20.9	144	2360	36.8	415	11900			
	51	20	″	64	1050	″	122	3525			
	75	30	″	43	699	″	76	2230			
	96	40	″	33	542	″	59	1695			
	115	50	″	28	453	″	49	1400			
	130	60	″	24	402	″	43	1245			
	141	70	″	22	367	″	39	1134			
	148	80	″	21.3	351	″	37.4	1080			
	150	90	″	20.9	345	″	36.8	1062			
175 FT.	30	10	24.5	167	3215	43	480	16190			
	60	20	″	74	1428	″	142	4790			
	88	30	″	50	953	″	90	3037			
	113	40	″	38	738	″	68	2305			
	134	50	″	32	616	″	57	[illegible]			
	152	60	″	29	546	″	50	1695			
	164	70	″	26	500	″	46	1543			
	171	80	″	24.9	478	″	44	1470			
	175	90	″	24.5	470	″	43	1445			
200 FT.	35	10	28	192	4200	49	548	[illegible]			
	68	20	″	85	1865	″	163	6260			
	100	30	″	57	1245	″	103	3965			
	129	40	″	44	963	″	78	3012			
	153	50	″	37	805	″	65	2494			
	173	60	″	33	[illegible]	″	57	2216			
	188	70	″	30	654	″	52	2017			
	197	80	″	28.4	623	″	50	1920			
	200	90	″	28	613	″	49	1890			
225 FT.	39	10	31	215	5315	55	617	26800			
	77	20	″	96	2361	″	183	7923			
	113	30	″	64	1575	″	116	5022			
	145	40	″	49	1219	″	88	3815			
	173	50	″	41	1020	″	73	3160			
	195	60	″	37	903	″	65	2804			
	211	70	″	34	826	″	58	2550			
	222	80	″	32	789	″	56	2430			
	225	90	″	31	776	″	55	2390			
250 FT.	43	10	35	239	6560	61	686	33080			
	86	20	″	106	2916	″	203	9780			
	125	30	″	71	1945	″	129	6200			
	161	40	″	55	1505		98	4770			
	192	50	″	46	1258	″	8	3900			
	217	60	″	41	1115	″	72	3460			
	235	70	″	37	1020	″	65	3150			
	246	80	″	36	974	″	62	3000			
	250	90	″	35	958		61	2950			
275 FT.	48	10	38	263	7940	68	754	39960			
	94	20	″	117	3525	″	223	[illegible]			
	138	30	″	78	2353	″	[illegible]	7500			
	177	40	″	60	1822	″	108	5700			
	211	50	″	50	1522	″	89	4720			
	236	60	″	45	1350	″	79	4287			
	258	70	″	41	1235	″	72	3800			
	271	80	″	39	1178	″	69	3690			
	275	90	″	38	1158	″	68	3370			
300 FT.	52	10	42	287	9450	74	823	47600			
	103	20	″	128	4297	″	244	14050			
	150	30		85	2800	″	154	5925			
	193	40	″	66	2168	″	[illegible]	6780			
	230	50		55	1822	″	97	5620			
	260	60		49	1606	″	86	4980			
	282	70		45	1470		79	4530			
	295	80		43	1402	″	75	4320			
	300	90		42	1380		74	4250			

A	B	C	FORM L-4 MEDIUM ANGLE D=12° W	L	AREA	FORM L-4 D=20° W	L	AREA	FORM L-11 D=16° W	L	AREA	FORM L-12 D=20° W	L	AREA	FORM L-12 D=30° W	L	AREA
25 FT.	43	10	5.25	47	94	8.8					63	8.8			34		
	86	20	″	7	69	″	34	233	″	24	94	″	34	233	″	86	900
	125	30	″		45	″	9	35	″	5	83	″	9	35	″	34	347
	161	40	″	8	34	″	14	100	″	7	68	″	14	100	″	23	243
	192	50	″	7	29	″	12	82	″	9	51	″	12	82	″	18	34
	217	60	″	6	25	″	10	72	″	8	45	″	10	72	″	16	[illegible]
	235	70	″	5.6	23	″	9.4	65	″	7.7	43	″	9.4	65	″	4.4	15
	246	80	″	5.3	22	″	9	62	″	7	[illegible]	″	9	62	″	3.6	49
	25	90	″	5.25	2	″	8.8	6	″	7	39	″	8.8	6	″	13.4	4
50 FT.	8.7	10	10.5	34	775	17.6			4.1	28.7	245	17.6			26.8		
	17	20	″	34	277	″	67	932	″	48	536	″	67	932	″	171	3400
	25	30	″	22	179	″	39	338	″	30	[illegible]	″	39	338	″	68	440
	32	40	″	17	38	″	29	398	″	23	249	″	29	398	″	47	980
	38	50	″	14	14	″	24	326	″	19	209	″	24	326	″	37	778
	43	60	″	12	100	″	21	287	″	18	80	″	21	287	″	32	667
	47	70	″	11	93	″	19	261	″	15.5	17	″	19	261	″	29	606
	49	80	″	10.7	88	″	18	248	″	4.9	57	″	18	248	″	27.2	573
	50	90	″	10.5	87	″	17.6	244	″	21	55	″	17.6	244	″	26.8	564
75 FT.	13	10	15.8	141	1745	26			21	333	5580	26			40		
	26	20	″	50	627	″	101	2100	″	[illegible]	1204	″	101	2100	″	187	8100
	38	30	″	33	403	″	58	1295	″	45	743	″	58	1295	″	62	3240
	48	40	″	25	310	″	43	835	″	34	567	″	43	835	″	70	2200
	57	50	″	21	256	″	35	733	″	28	463	″	35	733	″	55	743
	65	60	″	18	226	″	31	646	″	25	406	″	31	646	″	48	500
	70	70	″	17	208	″	28	586	″	23	384	″	28	586	″	43	1364
	74	80	″	16	198	″	27	558	″	24	354	″	27	558	″	4	290
	75	90	″	15.8	195	″	26	548	″	21	349	″	26	548	″	40	1268
100 FT.	17	10	21	88	3105	35			28	444	9800	35			54		
	34	20	″	68	1107	″	135	3740	″	37	24	″	35	3740	″	342	4390
	50	30	″	44	717		78	2150		60	920	″	78	2150	″	137	5750
	64	40	″	33	550	″	57	592	″	45	995	″	57	592	″	93	3900
	77	50	″	28	456	″	47	1305	″	37	82	″	47	1305	″	74	[illegible]
	87	60	″	24	402	″	41	1150	″	33	720	″	41	1150	″	63	2668
	94	70	″	22	371	″	38	1045	″	3	683	″	38	1045	″	58	2420
	99	80	″	21.3	352	″	36	992	″	29	630	″	36	992	″	55	2295
	100	90	″	21	346	″	35	977	″	28	621	″	35	977	″	54	2257
125 FT.	22	10	26	235	4850	44			35	555	15925	44			67		
	43	20	″	84	1728	″	169	5740	″	12	3335	″	69	2840	″	428	22500
	63	30	″	54	1120	″	97	3960	″	75	2062	″	97	3960	″	71	6900
	80	40	″	42	860		72	2488	″	56	545	″	72	2488	″	6	623
	96	50	″	35	772	″	59	2037		47	28		59	2037	″	92	4646
	108	60	″	30	626	″	5	1795		4	25	″	51	795	″	79	[illegible]
	118	70	″	28	579	″	47	630		39	1067	″	47	[illegible]	″	72	3789
	123	80	″	27	550	″	45	550		36	384	″	45	550	″	68	3482
	125	90	″	26	541	″	44	525		35	967	″	44	525	″	67	3425
150 FT.	26	10	31.5	282	6980	53			42	666	22000	53			80		
	51	20	″	101	2500		202	8990	″	45	4805	″	202	8390	″	33	32400
	75	30	″	65	608	″	117	4840	″	90	2970	″	117	4840	″	205	8930
	96	40	″	50	238	″	86	3580	″	67	2234	″	86	3380	″	139	8760
	115	50	″	42	025	″	7	2991	″	56	450	″	7	2930	″		6975
	130	60		37	904	″	62	2485	″	49	621	″	62	2585	″	95	6000
	141	70	″	34	834	″	57	2347	″	46	517	″	57	2347	″	86	8455
	148	80		32	792	″	54	2230	″	43	[illegible]	″	54	2230	″	82	5640
	150	90	″	31.5	780	″	53	2195		42	39		53	2195	″	80	5075



NOTE: FIGURES SHOWN ARE CLOSE APPROXIMATIONS ONLY

Fig. 6. Beam Data for Floodlighting Projectors

ment managers are trained in illumination matters and that this information be made available to their customers. The industrial plant manager can be shown where he is sacrificing labor and efficiency, production quality, and quantity because he is allowing glare to exist in his plant or the illumination is inadequate or incorrectly installed. The merchant may be shown where he can improve the lighting in his store by installing a more suitable system, how he can facilitate color matching by using color corrected lamps or equipment, or improve the attractiveness of his store by colored light. The householder can be shown how to make his lighting attractive, comfortable, and efficient, and suggestions offered for extending its usefulness.

The need for proper and adequate illumination exists today more than ever before, because the great European war has forced upon us the necessity for the efficient utilization of our materials. The fallacy of the indiscriminate curtailment of lighting has been established by Mr. Millar in his paper* before the Illuminating Engineering Society in which he showed that approximately only two per cent of the coal consumption of the country is used for electric light. The Government in its efforts to speed up production is requiring labor to extend its activities into the night with the consequent need for lighting. This lighting should be correctly installed and used if we are to conserve eyesight and health and obtain the maximum efficiency from our workmen.

* Lighting Curtailment, by Preston S. Millar, Transactions of the Illuminating Engineering Society, vol. XIII, No. 2.

Methods for More Efficiently Utilizing Our Fuel Resources

PART XVIII. THE CENTRAL STATION, ISOLATED PLANT, AND FUEL CONSERVATION

By G. F. Brown

Lighting Engineering Department, General Electric Company

There is much controversy relative to the desirability of shutting down isolated power plants and transferring the load to central stations. The author of this article takes as the basis of his argument the national fuel situation and by authentic facts and figures shows that the universal use of central-station power is to be emphatically recommended.—Editor.

In the past, little interest has been shown, generally, in proposed measures for the conservation of our fuel supply. They are now questions of first importance.

Coal Production and Consumption in the United States

The totals for all coal produced in the past three years are:

1915	532,000,000 tons
1916	600,000,000 tons
1917	650,000,000 tons

For 1916 the distribution of coal for various uses has been estimated as follows:

	Tons	Per Cent
Power and Steam*	250,000,000	42
Railroads	120,000,000	20
Other Industrials and Steamship bunker	110,000,000	18
Domestic	120,000,000	20

Although the production for 1917 was 50,000,000 tons greater than that for the preceding year, it was short of industry's requirements by 50,000,000 tons, according to statements of the Fuel Administration. It is estimated that the demand for coal for "Power and Steam" uses was 25 per cent greater in 1917 than in 1916; and for "Railroads" and "Industrial" uses, 33⅓ per cent greater. As these demands were not met by production, some plants were forced to slacken or suspend operation temporarily. The extent of this coal shortage can be reduced to a considerable extent by the efficient use of the coal that inefficient plants now waste.

* Steam used for heating and manufacturing processes.

Power and Steam Uses

Fully 40 per cent of the total coal output is burned under steam boilers for power purposes, heating, and manufacturing processes. In this group are the most economical users of coal; the central stations, some of which convert into power as high as 17 per cent of the energy in the coal. Exact figures are not available, but approximate figures indicate

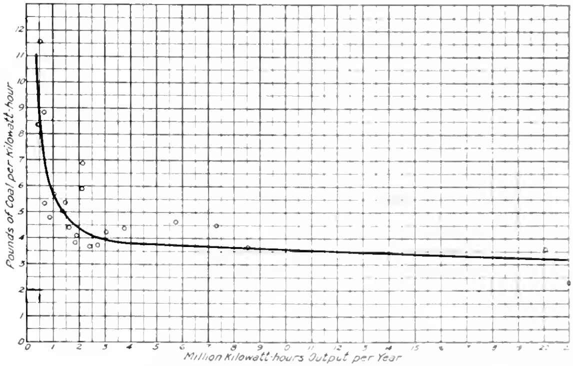


Fig. 1. Coal Consumption (1915) of Small Central Stations; Data from Tenth Annual Report Public Service Commission, State of New York

that the central stations use less than 10 per cent of the coal burned in this group, or less than 4 per cent of the total production. Most of the coal used by this group is burned in small plants, which in many cases do not recover one per cent of the energy of the coal they burn.

Coal Consumption of Electric Power Plants

The central station's sole business is the production of power. Economy of operation is of first importance. The station installs the most efficient machinery, employs expert engineers to supervise the operation, and keeps accurate records of all conditions affecting economy. The operation of the station amounts to a continuous test on the plant. Furthermore, such utilities are closely regulated by the State.

On the other hand, the isolated or private plant is only a side issue. Economy of operation is of secondary importance, as the power expense is only a small percentage of the production costs in the plant it serves. The small installation cannot afford to pay for expert supervision, it keeps no records, and its labor is usually of a low-grade character. The only check on its operation is the coal bill, but an investigation of an unusually large bill frequently stops at the excuse, "Bad run of coal." Isolated and private plants are not subject to regulation by the State. Fuel economy can be forced only by curtailing their supply; but this may not be advisable.

A plan is being considered to educate in the subject of operating economy those responsible for such plants. Something may be gained by such a plan, but the probable saving would be small compared to the amount which would be saved by substituting central-station power.

Fig. 1 shows the approximate coal consumption for small central stations. The large modern central station can produce power on $1\frac{1}{2}$ to $2\frac{1}{2}$ pounds of coal per kw-hr.

Fig. 2 is a similar curve for isolated plants and is drawn from published data. Coal for heating or manufacturing processes is not included.

If all the load of these isolated plants (Fig. 2) could be taken over by the central stations (Fig. 1), the minimum saving in coal would be about 10 per cent. If the load could be taken over by some of the larger central stations, the saving would be from 40 to 60 per cent.

Fig. 3 is an approximate comparison of fuel consumption (under test conditions)

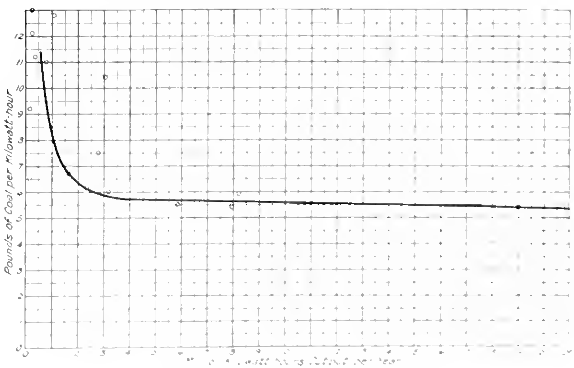


Fig. 2. Coal Consumption of Isolated Power Plants

of the apparatus used in different classes of electric power plants.

(*a*) Actual test of a 500-kw. engine-driven generating set operating condensing. This is a typical isolated plant installation, both as to equipment and operation. Due to careless operation, however, the yearly fuel consumption of this plant is fully 15 per cent greater than that indicated by the test curve.

(*b*) Results that could have been obtained in plant (a) by remodeling the boiler plant.

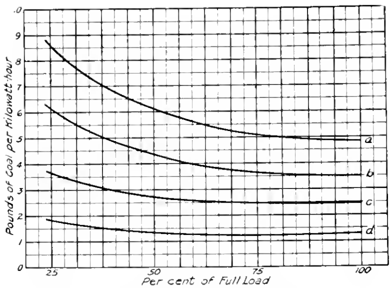


Fig. 3. Fuel Consumption (under test conditions) of apparatus used in different classes of electric power plants, at practical and full loads

(a) Actual test on 500-kw. isolated plant, reciprocating engine (condensing).
(b) Possible economy based on remodeling boiler plant of (a).
(c) Small turbo-generator plant.
(d) Large modern turbo-generator plant.

(*c*) Typical fuel consumption curve for a small turbo-generator such as is used by small central stations.

(*d*) Same as (c) except for a large modern turbo-generator such as is used by large central stations.

The fuel consumption of an electric power plant is affected to a considerable extent by the peak or maximum load which must be carried for a short time, and also by the size of the installation required to care for the maximum probable load.

The diversity-factor, which is the ratio of the maximum load on the plant (for the given period) to the sum of the maximum loads of the different classes of service, may be for the large plant only *one-quarter* that of the small plant.

The demand-factor, which is the ratio of the maximum load to the total connected load, for the large station is only about *one-half* that of the isolated plant.

Therefore the large station installs and operates much less equipment to handle a given load than would be required if the load were divided among small plants.

Load-factor, which is the ratio of the average load over a given period to the maximum load during this period, is a most important factor in the economical production of power.

The load-factor of the large central station is in the vicinity of 50 per cent; while that of the isolated plant is more often below 25 per cent than above it.

Low load-factor is much more serious for the isolated plant, with its single unit, than for the central station with several units. For example, in plant (*a*) Fig. 3 the maximum demand was about full load; the load-factor about 25 per cent. Hence, on the curve, it would require about 8.5 pounds of coal per kw-hr. As a matter of fact, it burned over 10 pounds of coal per kw-hr. The central station, on the other hand, operates only enough machines to carry the load at or near their point of maximum economy.

Saving by Use of Central Station Service

If all isolated and private power plants could be shut down and their load transferred to central stations, a large part of the necessary fuel saving would be accomplished. In the district served by one large utility, the possible saving has been estimated at not less than half a million tons per year. At this rate the total saving for the entire country should be between fifteen and twenty million tons. This plan is being strongly opposed, but the wastes of the inefficient plant must be checked if we are to save 50,000,000 tons of coal annually.

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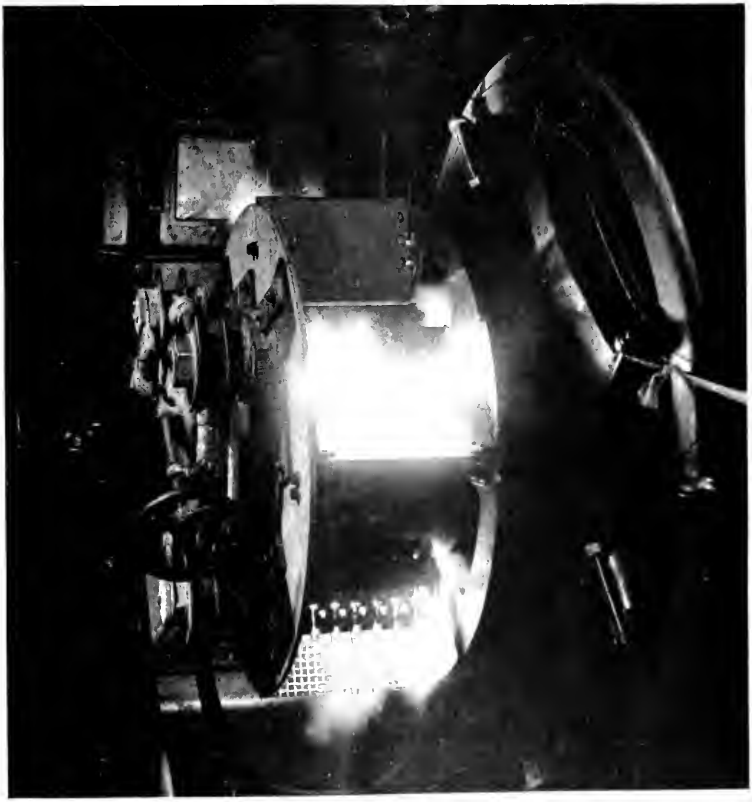

FLASHING AT THE COMMUTATOR, CAUSED BY SHORT CIRCUIT, ON A [illegible] KW [illegible]-VOLT SYNCHRONOUS CONVERTER SHOWING HOW THE ARC IS CONFINED AND AN ARC-OVER PREVENTED BY BARRIERS

(See page 499)

General Electric Review

A MONTHLY MAGAZINE FOR ENGINEERS

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July 1918

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SECRETARY OF NAVY DANIELS ADDRESSING WORKMEN AT SCHENECTADY PLANT OF GENERAL ELECTRIC COMPANY, JUNE 15TH

"I want to say to you men, you skilled laborers, you turbine builders, you constructors of gears and electrical apparatus—your place is here. Gentlemen, every day that you turn out more and better equipment for our Army and Navy, you are as truly fighting as are those brave men in the mud and glory of France."

GENERAL ELECTRIC REVIEW

PROTECTION AGAINST FLASHING ON DIRECT-CURRENT APPARATUS

Although direct-current apparatus has been greatly improved in commutating ability, it is still subject to flashing at the commutator under abnormal conditions of load. Before commutating poles were used, the range in load that could be handled without flashing on the higher voltage generators was limited because the best commutating position of brushes shifted considerably with changes in the load. The application of commutating poles permitted a fixed brush position for all loads, but they also introduced difficulties in the requirements of flux densities and distribution and in the timing of the flux with reference to load. Inability to attain this desired flux variation in the commutating poles, as the load changes, permits flashing to occur. This trouble has been experienced to a much greater extent on railway types of apparatus than on other types, due to the use of a ground return and to the necessity of collecting the current from many miles of overhead trolley or third rail. During the first few years of long distance railway development this difficulty was a very serious one, but it was gradually overcome to a great extent by improvements in the motor, generator, and synchronous converter design and to a greater extent by improvements in the trolley and control insulation which greatly reduced the number of grounds and short circuits.

Prevention of flashing has therefore offered a very fruitful field for the inventor, and a great many different schemes to accomplish it have been proposed.

The investigation described on page 499 of this issue was conducted to try out some of the most promising suggestions, and a careful persual gives a very good ideal of the rapid advance made and success obtained in practically making direct-current apparatus immune to damage from short circuits and in eliminating interruptions of service that would otherwise result from this cause.

The limiting of the short-circuit current by means of a high-speed device offers very attractive possibilities; and the several different types of recently developed apparatus, which have sufficient speed for this purpose, indicate that this advance in the art will without doubt have wide application in the future. It is interesting to note the success which has already been obtained with one of the high-speed devices in connection with the development of the 3000-volt, direct-current system for steam road electrification. The use of the special circuit breaker makes the operation of a 3000-volt, direct-current sub-station of large capacity as safe, simple, and peaceful as that of a small 600-volt sub-station.

The proposal to use barriers is almost as old as the direct-current generator itself, being one of the first protective measures proposed. It is evident that if means could be provided which would prevent an arc (developed under the brushes) from being communicated to the next brush or to the frame of the machine, sufficient time would be allowed for the switchboard circuit breaker to open and remove the excessive load. This proposal has been successfully developed through the use of a novel method of scooping the flash-over arc from the commutator and passing it through screens which dispose of it by cooling.

The application of this equipment on a synchronous converter will prevent arc-overs that may be caused by disturbances on the alternating-current side. It will also be effective in reducing the intensity of the flashing that may result from disturbances on the direct-current side of a synchronous converter or direct-current unit. The installation of the high-speed circuit breaker will eliminate damage to either type of unit which may be caused by disturbances on the direct-current side. The combination of the barrier equipment and the high-speed circuit breaker will fully protect a synchronous converter or direct-current unit from flashing.

America's Energy Supply*

THE AVAILABLE SOURCES OF ENERGY

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

The substance of this article goes to demonstrate that economical utilization of the country's energy supply requires that electric power be generated wherever hydraulic or fuel energy is available, this power to be collected electrically just as we distribute it electrically. A short survey of the country's energy supply in fuel and water power is made, and it is shown that the total potential hydraulic energy of the country is about equal to the total utilized fuel energy. It is shown that the modern synchronous station is necessary for large hydraulic powers, but that the solution of the problem of economic development of the far more numerous smaller water powers is the adoption of the induction generator, because of its simplicity of control. The characteristics of the induction generator and the induction generator station are reviewed. In the appendix is considered the problem of recovering wasted fuel power by interposing simple steam turbine induction generators between the boilers and the steam heating systems and collecting the power electrically, this being an appreciable part of the total available power in the fuel.—Editor.

Coal

The only two sources of energy which are so plentiful as to come into consideration in supplying our modern industrial civilization, are coal, including oil, natural gas, etc., and water power.

While it would be difficult to estimate the coal consumption directly, it is given fairly closely by the coal production, at least during the last decades, when wood as fuel became negligible; and export and import, besides more or less balancing each other, were small compared with production. Coal has been mined since 1822, and in Fig. 1 is recorded the coal production of the United States, from governmental reports. The annual production is marked by circles, and decennial average by crosses, every five years. Table I gives the decennial averages in millions of tons per year.

TABLE I

AVERAGE COAL PRODUCTION OF THE UNITED STATES

Year	Millions tons per year year	Per cent increase per year
1825	0.11	
1830	0.32	22.4
1835	0.83	19.7
1840	1.92	17.0
1845	4.00	14.5
1850	7.46	10.45
1855	10.8	8.35
1860	16.6	8.72
1865	25.9	9.22
1870	40.2	8.58
1875	56.8	7.42
1880	82.2	7.95
1885	122	6.80
1890	160	5.40
1895	206	5.75
1900	281	6.96
1905	404	6.60
1910	532	

* A paper presented at the thirty-fourth annual convention of the A.I.E.E., Atlantic City, June 1918.

† Soft coal and anthracite, and including oil reduced to coal by its fuel value.

As ordinates, in Fig. 1, are used the logarithms of the coal production in tons. With this scale, a straight line means a constant proportional increase, that is, the same percentage increase per year; and in the third column of Table I are given the average percentage increases of coal production per year.

Fig. 1 is of extreme interest in that it shows the great irregularity of production from year to year, and at the same time a very great regularity when extending over a long period of time. Since 1870 the average production can well be represented by a straight line, the values lying irregularly above and below the line, which represents an annual increase of 6.35 per cent, and thus the average coal production† C in the equation:

$$C=45.3\times 10^{0.0267\,(y-1870)} \text{ million tons}$$

or:

$$\log C=0.0267\,(y-1870)+7.656$$

where

$$y=\text{year}.$$

Before this time, from 1846 to 1884, the coal production could be represented by:

$$C=7.26\times 10^{0.0365\,(y-1850)} \text{ million tons}$$

or:

$$\log C=0.0365(y-1850)+6.861$$

representing an average annual increase of 8.78 per cent.

It is startling to note how inappreciable, on the rising curve of coal production, is the effect of the most catastrophic political and industrial convulsions, such as the Civil War, and the industrial panic of the early 90's; they are indistinguishable from the constantly recurring annual fluctuations. It means that the curve is the result of economic laws, which are laws of nature.

Extrapolating from the curve of Fig. 1, which is permissible due to its regularity, gives

867 million tons as this year's coal consumption. As it is difficult to get a conception of such an enormous amount, a comparison may illustrate it best: one of the great wonders of the world is the Chinese wall, running across the country for hundreds of miles, by which China unsuccessfully tried to protect its northern frontier against invasion. Using the coal produced in one year as building material, we could with it build a wall like the Chinese wall all around the United States, following the Canadian and Mexican frontiers, the Atlantic, Gulf, and Pacific coasts; and with the chemical energy contained in the next year's coal production, we could lift this entire wall 200 miles high into space. Or, with the coal produced in one year as building material, we could build 400 pyramids larger than the largest pyramid of Egypt.

It is interesting to note that:

One hundred thousand tons of coal were produced in the United States in	1825
The production reached one million tons in	1836
It reached ten million tons in	1852
It reached one hundred million tons in	1882
It will reach 1000 million tons about...	1920
and if continuing to increase at the same rate, it will reach 10,000 million tons in	1958

Estimating the chemical energy of the average coal as a little above 7,000 calories, *the chemical energy of one ton of coal equals approximately the electrical energy of one kilowatt-year (24-hour service)*. That is, one ton of coal is approximately equal in potential energy to one kilowatt-year.

Thus, the annual consumption of 867 million tons of coal represents in energy 867 million kilowatt-years.

However, as the average efficiency of conversion of the chemical energy of fuel into electrical energy is probably about 10 per cent, the coal production would be able, if converted into electrical energy, to give about 87 million kilowatts

Assuming, however, that only one half of the coal is used for power, at 10 per cent efficiency, the other half as fuel, for metallurgical work, etc., at efficiencies varying from 10 to 80 per cent, with an average efficiency of 40 per cent, we get in electrical measure 217 million kilowatts (24-hour service) as the total utilized energy of our present annual coal production of 867 million tons.

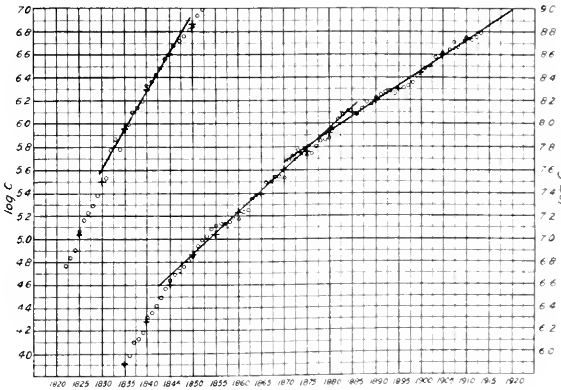


Fig. 1. Coal Production of the United States

Potential Water Powers of the United States

Without considering the present limitation in the development of water powers, which permits the use of only the largest and most concentrated powers, we may try to conceive the total amount of hydraulic energy which exists in our country, irrespective of whether means have yet been developed or ever will be developed for its complete utilization. We then proceed from the estimation of the energy of the total rainfall

Superimposing the map of rainfall in the United States upon the map of elevation, we divide the entire territory into sections by rainfall and elevation This is done in Table II for that part of our continent between 30 and 50 degrees northern latitude.

As obviously only the general magnitude of the energy value is of interest, but few subdivisions have been made: five of rainfall and four of elevation, as recorded in columns 1 and 2 of Table II.* The third column then gives the area of each section, in millions of square kilometers; the fourth column the estimated average elevation in meters, and the fifth column the average rainfall in centimeters. The sixth column then gives the energy, in kg-m. per m^2 of area; and the last column the total energy of the section in kg-m. which would be represented by the rainfall if the total hydraulic energy of every drop of rain were counted, from the elevation where it fell down to the sea level.

* The lowest elevation, < 100 feet is not included, as having little potential energy.

As seen from Table II, the total rainfall of the North American continent between 30 and 50 degrees latitude represents 3000×10^{15} kg-m. This equals 950 million kilowatt-years (24-hour service). That is, the total potential water power of the United States, or the hydraulic energy of the total rainfall, from the elevations where it fell, down to sea level, gives about 1000 million kilowatts.

However, this is not available, as it would leave no water for agriculture; and, even if the entire country were one hydraulic development, there would be losses by seepage and evaporation.

An approximate estimate of the maximum potential power of the rainfall, after a mini-

TABLE II

TOTAL POTENTIAL WATER POWER OF UNITED STATES

Rainfall In.	Elevation feet	Area $\frac{m^2}{10^{12}}$	Average elevation meters	Average rainfall Cm.	$\frac{kg\text{-}m.}{10^3}$ per m^2	Total $\frac{kg\text{-}m.}{10^{15}}$
< 10	>5000	0.54	2100	12.5	263	142
	1000–5000	0.29	900		112	32.5
10–20	5000	1.18	2100	37.5	787	930
	1000–5000	1.96	900		338	660
20–30	1000–5000	0.32	900	62.5	563	183
	100–1000	0.97	150		94	91
30–40	1000–5000	0.35	900	87.5	786	275
	100–1000	1.40	150		131	184
40–60	1000–5000	0.27	900	125	1130	305
	100–1000	1.03	150		188	194
	Total					2996
	Approximately					3000

TABLE III

AVAILABLE POTENTIAL WATER POWER OF THE UNITED STATES

Average rainfall Cm.	Average elevation M	Area $\frac{m^2}{10^{12}}$	Wastage Cm.	Agriculture Cm.	Available rainfall Cm.	$\frac{kg\text{-}m}{10^3}$ per m^2	Total $\frac{kg\text{-}m.}{10^{15}}$
12.5	2100	0.54	12.5	..	..	..	..
	900	0.29	12.5		..	..	..
37.5	2100	0.39	12.5	25	..	..	..
	2100	0.79	12.5	..	25	525	415
	900	0.98	12.5	25	..	..	..
	900	0.98	12.5	..	25	225	220
62.5	900	0.21	12.5	37.5	12.5	112	23
	900	0.11	12.5	..	50	450	50
	150	0.97	12.5	37.5	12.5	19	18
87.5	900	0.35	12.5	37.5	37.5	337	118
	150	1.40	12.5	37.5	37.5	56	78
125	900	0.27	12.5	37.5	75	674	182
	150	1.03	12.5	37.5	75	112	116
Total							1220

mum allowance for agriculture and for losses, is made in Table III. In this, 12.5 cm. rainfall has been allowed for wastage, and 25 and 37.5 cm. respectively, for agriculture where such is feasible.

This gives as total available potential energy about 1200×10^{15} kg-m., or 380 million kilowatts (24-hour service).

Assuming now an efficiency of 60 per cent from the stream to the distribution centers, there remain 230 million kilowatts (24-hour service) as the maximum possible hydro-electric power which could be produced if, during all seasons, every river, stream, brook, or little creek throughout its entire length from the spring to the ocean, together with all the waters of the freshets, could be and were used. It would mean that there would be no running water in this country, in fact, there would be only stagnant pools connected by pipe lines to turbines exhausting into the next lower pool. Obviously, we could never reasonably hope to develop more than a part of this power.

Discussion

It is interesting to note that the maximum possible hydraulic energy of 230 million kilowatts is little more than the total energy which we now produce from coal, and is about equal to the present total energy consumption of the country including *all* forms of energy.

This is rather startling. It means that the hope that when coal once begins to fail we may use the water powers of the country as source of energy is and must remain a dream; for if today all the potential water power of the country were developed and every rain drop used it would not supply our present energy demand.

Thus hydraulic power may and should supplement coal as a source of power, but can never replace it.

This probably is the strongest argument for efforts to increase the efficiency of our means of using coal.

The source of energy, which is practically unlimited, if it only could be used, is solar radiation. Estimating the solar radiation at the earth surface as 1.4 calories per sq. cm. per min. would give, per sq. cm. horizontal surface between latitudes 30 and 50, assuming 50 per cent cloudiness, an average throughout the year (24 hours per day) of about 0.14 calories per sq. cm. horizontal surface per min. and on the total area of North America, between 30 and 50 latitude, 8.3 million square kilometers, a total of approximately 800,000 million kilowatts (24-hour service)—a thousand times as much as the total chemical energy of our coal consumption, or 800 times as much as the potential energy of the total rainfall.

Considering that the potential energy of the rainfall—from surface level to sea level—is a small part of the potential energy spent by solar radiation in raising the rain to the clouds, and that this is a small part of the total solar radiation, the foregoing is reasonable.

Considering only the 2.7 million square kilometers of Table III, which are assumed as unsuited for agriculture, and assuming that, in some future time and by inventions not yet made, half of the solar radiation could be collected, this would give an energy production of 130,000 million kilowatts.

Thus, even if only one tenth, or 13,000 million kilowatts, of this could be realized, it would be many times larger than all the energy of coal and water power. Here then would be the great source of energy for the future.

HYDRO-ELECTRIC STATIONS

The Modern Synchronous Generator Station

In developing the country's water powers, thus far only those of greatest energy concentration have been considered, that is, those where a large volume and a considerable head of water were available within a short distance.

This led, as the best solution for the problem, to the present type of hydro-electric generating station, comprising:

- Three-phase synchronous generators, directly connected to
  - Hydraulic turbines of the highest possible efficiency.
  - Speed-governing mechanism for hydraulic turbines.
  - An exciter plant comprising:
    - Either exciters directly connected to the generators or several separate exciters connected to separate turbines.
    - Exciter busbars.
    - Voltmeter, and ammeters in exciter armature and alternator field circuits.
    - Field rheostats for the alternators.
  - Low-tension busbars, either in duplicate or with transfer or synchronizing bus.
  - Circuit breakers between generators and busbars, usually non-automatic.
  - Circuit breakers between transformers and busbars, usually automatic, with time limit.
  - Voltmeters and potential transformers at the generators supplying:
    - Synchroscopes or other synchronizing devices.
    - Ammeters and current transformers at the generators
    - Voltmeter and potential transformer at the busbar.

Ammeters and current transformers at the step-up transformers
Totaling ammeter for the station output.
Integrating wattmeter.
Relays, interlocking devices, etc., etc.
Step-up transformers.
High-tension busbars, possibly in duplicate.
High-tension circuit breakers between transformers and high-tension busbars.
High-tension circuit breakers between high-tension busbars and lines.
Lightning arresters in the transmission lines, with inductances, etc.
Ground detectors, arcing-ground or short-circuit suppressors, voltage indicators, etc.
Automatic recording devices (multi-recorder): rarely used, though very desirable.

It will be seen that, due to the high powers controlled by modern stations, the auxiliary and controlling devices in these stations have become so numerous as to make the station a complex structure requiring high operating skill and involving high cost of installation.

Not only are all these devices necessary for the safe operation of the station, but at the same time it must be expected that, with the further increase of power of our electric systems, additional devices will become necessary for safe and reliable operation. One such device I have already mentioned, viz., the automatic recording apparatus, such as the multi-recorder.

With this type of station it obviously is not possible, in most cases, to develop water powers of small and moderate size, and a generating station of a thousand horse power will rarely, or one of a hundred horse power hardly ever, be economical.

On the other hand, a hundred horse power motor installation is a good economical proposition, and the average size of all the motor installations is probably materially below one hundred horse power.

Looking over Table II, and especially Table III in the preceding section, it is startling to see how large a part of the potential water power of the country is represented by relatively small areas of high elevation, in spite of the relatively low rainfall of these areas. As most of these areas are at considerable distances from the ocean, most of the streams are small in volume. That is, it is the many thousands of small mountain streams and creeks, of relatively small volume of flow but with high gradients affording fair heads, which apparently make up the bulk of the country's potential water power.

Only a small part of the country's hydraulic energy is found so concentrated locally as to make its development economically feasible with the present type of generating station. Therefore *some different and very much simpler type of generating station must be evolved before we can attempt to economically develop these many thousands of small hydraulic powers, and collect the power of the mountain streams and creeks.*

Simplification of Hydro-electric Station

The following discussion of the simplification of the hydroelectric station to adapt it to the utilization of smaller powers is limited to the case where smaller hydraulic stations feed into a system containing some large hydraulic or steam-turbine stations from which the system may be controlled.

We may eliminate the low-tension busbars, with generator circuit breakers and transformer low-tension circuit breakers, and connect each generator directly to its corresponding transformer, making one unit of generator and transformer, and do the switching on high-tension busbars which, with the circuit breakers, can be located outdoors. While it is dangerous to transformers to perform the switching on the high-tension side, due to the possibility of cumulative oscillations, this danger is reduced by the permanent connection of the transformer to the generator circuit, and is less with the smaller units used in small power stations, and therefore permissible in this case. However, the simplification effected is pronounced, since ammeters, voltmeter and synchronizing devices with their transformers are still retained on the low-tension circuits.

Since it is not economical to operate at partial load, proper operation of a hydraulic station on a general system requires that as many units operate fully loaded as there is water available for, and to increase or reduce the number of units (of turbine, generator and transformer, permanently joined together) with the changing amount of available water, thus using all the energy of which the water is capable.

In this case the turbine governors, with their more or less complex hydraulic machinery, may be omitted. If then the generators are suddenly shut down by a short circuit which opens the circuit breakers, the turbines will race (run up to their free running speed) until the gates are shut by hand. However, generators and turbines must be able to stand this, as even by the use of governors the turbines may momentarily run up to their free speed, in case of a sudden opening of the load, before the governors can cut off the water. Where this is not desirable, some simple excess speed cut-off may be used.

When eliminating the governing of the turbines and running continuously at full load, the question may be raised whether generator ammeters are necessary, as the load is constant and is all the power that the water can give. With synchronous generators, however, the current depends not only on the load, but also on the power-factor of the load, and with excessively low power-factor due to wrong excitation the generators may be overheated by excess current, while the power load is well within their capacity. Thus ammeters are necessary with synchronous generators. As soon, however, as we drop the use of synchronous generators and adopt induction generators, the ammeters with their current transformers may be omitted, since the current and its power-factor are definitely fixed by the load. At the same time, synchronizing devices, together with potential transformers, generator voltmeters, etc., become unnecessary. A station voltmeter may be retained for general information but is not necessary, as the voltage and frequency of the induction generator station are fixed by the controlling synchronous main station of the system.

With the adoption of the induction generator the entire exciter plant is eliminated, as the induction generator is excited by lagging currents received from synchronous machines, transmission lines, and cables existing in the system. Thus are dispensed with the exciters, exciter buses, ammeters, voltmeters, alternator field rheostats, etc.; in short, most of the auxiliaries of the present synchronous station become unnecessary.

Thus, *the solution of the problem of the economic development of smaller water powers is found in the adoption of the induction generator.*

Stripped of all unnecessaries, the smaller hydroelectric station would comprise:

- Hydraulic turbines of simplest form, continuously operating at full load, without governors.
- Low-voltage induction generators directly connected to the turbines.
- Step-up transformers directly connected to the induction generators.
- High-tension circuit breakers connecting the step-up transformers to the transmission line. In smaller stations, even these may be dispensed with and replaced by disconnecting switches and fuses.
- Lightning arrester on the transmission line, where the climatic or topographical location makes these necessary.
- A station voltmeter, a totaling ammeter or integrating wattmeter and a frequency indicator may be added for the information of the station attendant, but are not necessary, as voltage, current, output, and frequency are not controlled from the induction generator station, but from the main station, or are determined by the available water supply.

It is interesting to compare this induction generator station lay-out with that of the modern synchronous station on page 457. However, it must not be forgotten that *the simplicity of the induction generator station results from the transference of all the functions of excitation, regulation, and control to the main synchronous stations of the system*, and thus the induction generator stations are feasible only as adjuncts to at least one large synchronous station (hydraulic or steam turbine) in the system, but can never replace the present synchronous generator stations in their present field of application.

Automatic Generating Stations

With the enormous simplification resulting from the use of the induction generator it appears entirely feasible to make smaller hydroelectric generating stations entirely automatic, that is, operating without attendance beyond occasional (weekly or daily) inspection.

Such an automatic generating station would comprise a turbine with low-voltage induction generator housed under a shed, and an outdoor step-up transformer connected into the transmission line with time fuses and disconnecting switches.

It is true that in the big synchronous generating stations of thousands of kilowatts, the cost of the auxiliaries, such as exciter plant, regulating and controlling devices, etc., is only a small part of the total station cost, and little would therefore be saved by the use of induction generators. No induction generators would, however, be used for such stations. But the cost of auxiliaries and controlling devices, and the cost of the required skilled attendance decrease far less with decreasing station size than that of the generators, whether synchronous or induction, or, in other words, with decreasing size of the station (*per kilowatt output*) the cost of auxiliaries and controlling devices, and of attendance, increases at a far greater rate than that of the generators, and very soon makes the synchronous station of the present type uneconomical.

It is also true that, in the big modern hydraulic power systems, the cost of the generating station usually is a small part of the cost of the hydraulic development. Therefore, any saving in the cost of the generating station would be of little influence in determining whether the hydraulic development would be economical. With decreasing size of the water power the cost of the hydraulic development *per kilowatt output* usually increases so rapidly as to very soon make the development of the water power uneconomical, no matter how simple and cheap the station is.

However, the value of the induction generator lies not so much in the reduction of the cost of the generating station as in the reduction of the cost of the hydraulic development, through making it possible to apply to the electric generator the same principle which has made the electric motor economically so successful. *Collect the power electrically just as we distribute it electrically.*

We do not, as in the days of the steam engine, convert the electric power into mechanical power at one place by one big motor and distribute it mechanically by belts and shafts; but we distribute the power electrically, by wires, and convert the electric power to mechanical power, wherever mechanical power is needed, by individual motors throughout mill and factory.

In the same way we must convert the hydraulic, that is, the mechanical power, into electrical power by individual generators located along the streams or water courses within the territory, wherever power is available, and then collect this power electrically by medium-voltage collecting lines and high-voltage transmission lines, and so eliminate most of the cost of the hydraulic development, to solve the problem of the economical utilization of the country's water powers. If we attempt to collect the power mechanically, that is, by a hydraulic development which gathers the waters of all the streams and creeks of a territory together into one big station and there converts it into electric power, the cost of the hydraulic development makes it economically hopeless except under unusually favorable conditions where a very large amount of power is available within a limited territory, or where nature has done the work for us in gathering considerable power at a waterfall, etc.

It is the old problem and the old solution: If you want to *do it economically, do it electrically.*

Naturally then, we would use induction generators in these small individual stations, just as we use induction motors in individual motor installations, but, where large power is available, there is the field of the synchronous generator, where the induction generator is undesirable, just as the synchronous motor is preferable where large power is required—unless the synchronous motor is excluded by conditions of starting torque, etc.

At first, and for some time to come, we would not consider going down to sizes of induction generators anywhere near as small as are common in induction motors. However, throughout the country, there are undoubtedly many millions of kilowatts available in water powers which can be collected by induction generator stations from 50 horse power upwards, and which at fair heads, would require no abnormal machine design (no very slow speed).

Consider the instance of a New England river with a descent in its upper course of about 1100 feet of varying gradient within five miles: at three places where the gradient is steepest, by a few hundred feet of cast-iron pipe and a small dam of 20 to 30 feet length and a few feet height (just enough to cover the pipe intake), an average head of 150 feet can be secured, giving an average of 75 horse power each, or a total of 225 horse power or 170 kilowatts. This would use somewhat less than half the total potential power. The development of the other half, requiring greater length of pipe line or involving lower heads, would be left to meet future demands for additional power.

The installation of an electric system with 170 kilowatts would hardly be worth while; but there are numerous other creeks throughout the territory from which to collect power and which within a few miles pass high potential transmission lines, coming from big synchronous stations into which the power-collecting lines from the induction generator stations could be tied and from which they could be controlled.

Thus, the large modern synchronous station has its field and is about as perfect as we know how to build stations for large concentrated powers; but beyond this there is a vast field, and therefore an economic necessity for the development of a different type of hydraulic generating station to collect the scattered water powers of the country, and that is the induction generator station, to which it is desired to draw attention.

Caution must be exercised, however, not to mistake small power and low-head power. There are, on the lower courses of our streams, some hydraulic powers which are relatively small due to their low heads and which cannot be economically developed by the synchronous generator due to the low head and correspondingly low speed. The designing characteristics of the induction generator, with regard to slow-speed machines, are no better—if anything rather worse—than those of the synchronous generator, and the problem of the economical utilization of the low head water power still requires solution. It is not solved by the induction generator; the latter's characteristic is simplicity of the station, giving the possibility of numerous small automatic generating stations.

INDUCTION GENERATOR STATION

Characteristics of Induction Generator

An induction motor at no load runs at or rather very close to synchronism. If it is driven above synchronism by mechanical power, current and power again increase, but the electric power is outflowing, and the induction machine consumes mechanical power and generates electrical power as an induction generator.

The maximum electrical power which an induction machine can generate as induction generator is materially larger than the maximum mechanical power which the same machine at the same terminal voltage can produce as induction motor.

Resolving the current of the induction machine into an energy component and a wattless or reactive component, the energy current is inflowing, representing consumption of electric power (which is converted to mechanical power) below synchronism. It becomes zero at synchronism. Above synchronism, the energy current is in the reverse direction, or outflowing, supplying electric power to the system (which is produced from the mechanical power input into the machine), and the induction machine is then a generator.

The wattless or reactive component is a minimum at synchronism, increasing with the slip from synchronism, and is in the same direction, whether the slip is below synchronism (as motor), or above synchronism (as generator). That is, the induction machine always consumes a lagging current (representing the exciting current and the reactance voltages), or, what amounts to the same thing, produces a leading current. The latter way of putting it is frequently used with reference to induction generators, by saying that the current produced by the induction generator is leading, while the current consumed by the induction motor is lagging. Instead of saying, however, that the reactive component of the current generated by the induction generator is leading, it may be said —and this often makes it more intelligible—that the induction generator generates an energy current and consumes a lagging reactive current, and that the induction motor consumes an energy current and also a reactive lagging current.

Since the leading currents taken by transmission lines and underground cables are becoming increasingly larger with the incresaing voltages and increasing extent of our transmission systems, the induction generator appears especially advantageous as tending to offset the effect of line capacity. Thus, it may be said that the induction generator (and induction motor) consumes a lagging reactive current which is supplied by the synchronous generators, synchronous motors, converters, and other synchronous apparatus in the system, and by the capacity of lines and cables; or, it may be said that the lagging current consumed by the induction generator neutralizes the leading current consumed by the capacity of lines and cables. Or, again, it may be said that the leading current produced by the induction generator supplies the capacity of lines and cables. These are merely three different ways of expressing the same facts.

In Fig. 2 are shown the torque curves, at constant terminal voltage, of a typical moderate-sized induction machine. *M* is the torque produced as induction motor below synchronism, and *G* the torque consumed as induction generator above synchronism, synchronism being chosen as 100 per cent. *T* is added as an assumed torque curve of a hydraulic turbine.

As may be seen, the point *P*, where *G* and *T* intersect, is 4 per cent above synchronism and, thus, this induction generator operates on full load at 4 per cent slip above synchronism or no load. Now, assume that the power goes off through the opening of the circuit breakers. The turbine then speeds up to 80 per cent above synchronism, where the curve *T* becomes zero. If at this free running turbine speed the circuit is closed and voltage put on the induction generator, the high torque consumed by the induction generator will cause the turbine to slow down and, as at all speeds above 104 per cent the torque consumed by the induction generator is very much higher than that given by the turbine, the machines will slow down rapidly to the speed where the induction generator torque is equal to the turbine torque, (speed 104 per cent), and stable condition is restored.

Inversely, if the flow of water should cease, the induction machine slows down to a little below synchronism and there continues to revolve as induction motor.

With larger machines the most satisfactory way of starting, and that involving the least disturbance, probably would be, first, to open the gates partly, and while the turbine speeds up into the neighborhood of synchronism, say between 95 and 105, to close the circuit and open the water gates fully.

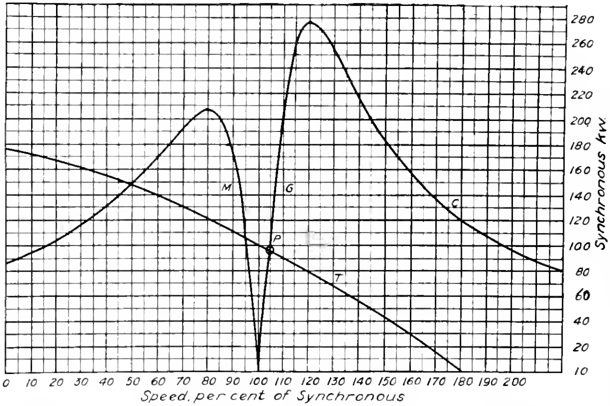


Fig. 2. Small Hydro-electric Induction Generator Plant. Constant Terminal Voltage

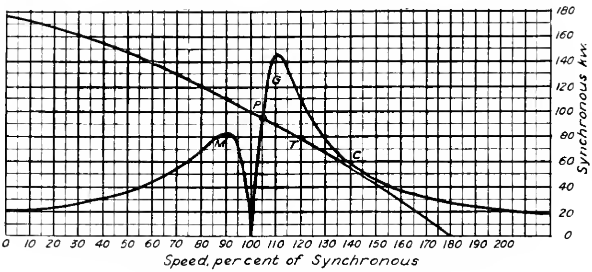


Fig. 3. Small Hydro-electric Induction Generator Plant. Constant Voltage in Synchronous Main Station

In starting, the circuit may be closed before admitting water to the turbine, the turbine being started by the induction machine as motor, on the torque curve M, and run up to speed 100, and then, by admitting the water, the machine may be speeded up 4 per cent more and thereby made to take the load as generator. Or the turbine may be started by opening the gates, running up to speed 180, and then, by closing the circuit, the induction machine will slow down to normal in taking the load.

Instability Conditions of Induction Generator

In Fig. 2 the torque consumed by the induction machine at all turbine speeds above full load P is much higher than the torque of the turbine. However, the induction generator torque curve has a concave range, marked by C, and if the induction generator should be such as to bring the generator torque curve at C below the turbine torque curve T, the speed, when once increased beyond the range C, would not spontaneously drop back to normal. While C in Fig. 2 is much higher than T, C represents the theoretical but not the real case of constant terminal voltage at the induction machine. The voltage, however, is kept constant at the controlling synchronous main station, and thus must vary with the load in the induction generator station. Assuming an extreme case of 10 per cent resistance and 20 per cent reactance in the line from the induction machine station to the next synchronous station, the modified torque curve shown in Fig. 3 is obtained. As seen, at full load P there is practically no change, about 4 per cent slip above synchronism. The maximum torque of generator G and motor M and the torque at the concave part of the induction generator curve C, have greatly decreased. However, C is still above T, that is, even under this extreme assumption the induction generator will pull the turbine down from its racing speed of 180 to the normal full load speed of 104, though the margin has become narrow.

Assume, however, an induction machine with much less slip and with only half the rotor resistance of that of Figs. 2 and 3.

At constant terminal voltage this gives the curves shown in Fig. 4. The full load P is at speed 102, or 2 per cent above synchronism, and while the curve branch C is much lower, conditions are still perfectly stable. Assume, however, with this type of low resistance rotor these conditions: a high line impedance, 10 per cent resistance, and 20 per cent reactance, as in Fig. 3. The condition shown in Fig. 5 then results. The range C drops below T, and the induction generator torque curve G intersects the turbine torque curve T at the three points: P, P_1, and P_2. Of these three theoretical running speeds ($P=102$, $P_1=169$ and $P_2=113.5$), two are stable, P and P_1; while the third one, P_2, is unstable; and from P_2 the speed must either decrease, reaching stability at the normal full load point P, or increase to P_1.

If, with the conditions represented by Fig. 5, the turbine should, through an opening of the circuit for instance, have speeded up to its free running speed of 180, the closing of the circuit does not bring the speed back to normal P, but only to speed P_1, where stability is reached, with very little output and very large lagging currents in the induction generator. To restore the normal condition would then require shutting off the water, at least sufficiently to drop the turbine torque curve T below C, and then letting the machine slow down to synchronism. They would not go below synchronism, even with the water gates entirely closed, as the induction machine as motor, on curve M, holds the speed.

A solution in the case, Fig. 5, would be the use of a simple excess-speed governor which cuts off the water at 5 to 10 per cent above synchronism.

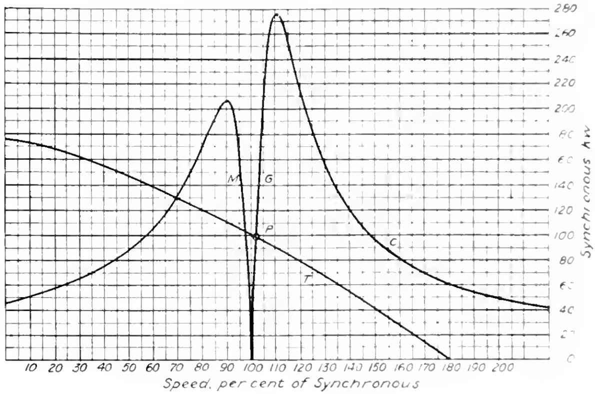


Fig. 4. Large Hydro-electric Induction Generator Plant. Constant Terminal Voltage

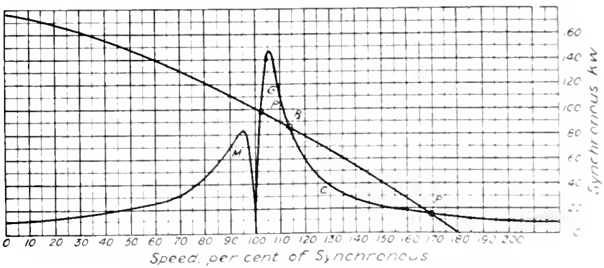


Fig. 5. Large Hydro-electric Induction Generator Plant. Constant Voltage in Synchronous Main Station

However, the possibility of difficulty due to the dropping out of the induction generator as it may be called in analogy to the dropping out of the induction motor, is rather less real than appears theoretically. In smaller stations, such as would be operated without attendance, as for example automatic stations, the torque curve of the induction generator, as a small machine, would be of the character of Figs. 2 and 3, and thus not liable to this difficulty. The very low resistance type of induction machines, as represented in Figs. 4 and 5, would embrace only the larger machines used in larger stations. In these stations, some attendant would be present to close the water gates in case the circuit breakers should open, or a simple and inexpensive excess-speed cut-off could be installed at the turbines to keep them within 10 per cent of synchronism, and within this range no dropping out of the induction generator can occur.

It is desirable, however, to realize this speed range of possible instability of the induction generator, so as to avoid it in the design of the induction generators and stations.

APPENDIX

COLLECTION OF FUEL POWER BY STEAM TURBINE INDUCTION GENERATOR

A. The Automatic Steam Turbine Induction Generator Station

The same reason which in the preceding led to the conclusion that in the (automatic) induction generator station is to be found the solution of the problem of collecting the numerous small amounts of hydraulic energy, which are scattered throughout our country along creeks and mountain streams, also applies, and to the same extent, to the problem of collecting the innumerable small quantities of mechanical or electrical energy, which are, or can be made available wherever fuel is consumed for heating purposes. Of the hundred millions tons of coal which are annually consumed for heating purposes, most is used as steam heat. Suppose then, we generate the steam at high pressure —as is done already now in many cases for reasons of heating economy—and interpose between steam boiler and heating system some simple form of high pressure steam turbine, directly connected to an induction generator, and tie the latter into the general electrical power distribution system. Whenever the heating system is in operation, electric power is generated, we may say as "by-product" of the heating plant, and fed into the electric system.

The power would not be generated continuously, but mainly in winter, and largely during the day and especially the evening. That is, the maximum power generation by such fuel power collecting plant essentially coincides with the lighting peak of the central station, thus occurs at the time of the day, and the season when power is most valuable. The effect of such fuel power collection on the central station should result in a material improvement of the station load factor, by cutting off the lighting peaks.

The only difference between such steam turbine induction generator stations, collecting the available fuel power scattered throughout the cities and towns, and the hydraulic induction generator stations collecting the powers of the streams throughout the country, is that in the steam turbine plant an excess speed cut-off must be provided, as the free running steam turbine speed is usually not limited to less than double speed, as is the case with the hydraulic turbine. Otherwise, however, no speed governing is required. A further difference is, that the greater simplicity and therefore lower investment of the steam turbine plant would permit going down to smaller powers, a few kilowatts perhaps.

It is interesting to note, that even with a very inefficient steam turbine, the electric generation of such fuel power collecting plant interposed between boiler and heating system, takes place with practically 100 per cent efficiency, because whatever energy is wasted by the inefficiency of the steam turbine plant, remains as heat in the steam, and the only loss is the radiation from turbine and generator, and even this in most cases is useful in heating the place where the plant is located. The only advantage of a highly efficient turbine, is that larger amounts of electric power can be recovered from the fuel, and the question thus is that between the investment in the plant, and the value of the recovered power.

If, then, the total efficiency, from the chemical energy of the fuel to the electric power, were only 3 per cent, it would mean that 3 per cent more coal would have to be burned, to feed the same heat units into the heating system. At an average energy value of 30,000 kj. per kg. of coal, this would give per ton of coal, 900,000 kj. or 250 kw-hr. At a bulk value of ½ cent per kw-hr. it would represent a power recovery value of $1.25 per ton of coal. This is quite considerable, more than sufficient to pay the interest on the investment in the very simple plant required.

At first, the steam turbine induction generator plant, proposed for the collection of fuel power, would appear similar to the isolated plant, which, though often proved uneconomical, still has successfully maintained its hold in our northern latitudes where heating is necessary through a considerable part of the year. However, the difference between the steam turbine induction generator plant and the isolated steam electric plant in our cities, is the same as that between the automatic hydroelectric induction generator station, and the present standard synchronous generator station: by getting rid of all the complexity and complication of the latter, the induction generator station becomes economically feasible in small sizes; but it does so only by ceasing to be an independent station in turning over the functions of regulation and control to the central main station and so becoming an adjunct to the latter. But by this very feature, the turbo induction generator plant might afford to the central station, the public utility corporation, a very effective means of combating the installation of isolated plants by relieving the prospective owner of the isolated plant of all trouble, care, and expense and incidental unreliability thereof, supplying central station power for lighting but at the same time utilizing the potential power of the fuel burned for heating purposes. The simplest arrangement probably would be, that the fuel power collecting plants scattered throughout the city would, as automatic stations, be taken care of by the public utility corporation, their power paid for at proper rates (those of uncontrolled bulk power) while the power used for lighting would be bought from the central station at the proper lighting rates.

As this, however, means a new adjustment of the relation between customer and central station, and is not merely an engineering matter like the hydroelectric power collection, I have placed it in an appendix.

B. Discussion

We realize that our present method of using our coal resources is terribly inefficient. We know that in the conversion of the chemical energy of coal into mechanical or electrical energy, we have to pass through heat energy and thereby submit to the excessively low efficiency of transformation from the low-grade heat energy to the high-grade electrical energy. We get at best 10 to 20 per cent of the chemical energy of the coal as electrical energy; the remaining 80 to 90 per cent we throw away as heat in the condensing water, or worse still, have to pay for getting rid of it. At the same time we burn many millions of tons of coal to produce heat energy, and by degrading the chemical energy into heat, waste the potential high-grade energy which those millions of tons of coal could supply us.

It is an economic crime to burn coal for mere heating without first taking out as much high-grade energy, mechanical or electrical, as is economically feasible. It is this feature, of using the available high-grade energy of the coal, before using it for heating, which makes the isolated station successful, though it has every other feature against it. To a limited extent, combined electric and central steam-heating plants have been installed, but their limitation is in the attempt to distribute heat energy, after producing it in bulk, from a central station. Here again we have the same rule; to do it efficiently, do it electrically. In the efficiency of distribution or its reverse, collection, no other form of energy can compete with electric energy, and the economic solution appears to be to burn the fuel wherever heating is required, but first take out its available high-grade energy, and collect it electrically.

Assume we use 200 million tons of coal per year for power, at an average total efficiency of 12 per cent, giving us 24 million kw. (referred to 24-hour service) and use 200 million tons of coal for heating purposes, wasting its potential power.

If then we could utilize the waste heat of the coal used for power generation, even if thereby the average total efficiency were reduced to 10 per cent, we would require only 240 million tons of coal, for producing the power, and would have left a heating equivalent of 216 million tons of coal, or more than required for heating. That is, the coal consumption would be reduced from 400 million to 240 million of tons, a saving of 160 million tons of coal annually.

Or, if from the 200 million tons of coal, which we degrade by burning for fuel, we could first abstract the available high-grade power, assuming even only 5 per cent efficiency, this would give us 10 million kw. (24-hour rate), at an additional coal consumption of 10 million tons, while the production of the 10 million kw. now requires 100 million tons of coal, more or less, thus getting a saving of 90 million tons of coal, or putting it the other way, a gain of 9 million kw. 12 million horse power 24-hour service, or 36 million horse power for an 8-hour working day.

It is obvious that we never could completely accomplish this; but even if we recover only one quarter, or even only one tenth of this waste, it would be a vast increase in our national efficiency.

Thus the solution of the coal problem, that is, the more economic use of fuel energy, is not only the increase of the thermodynamic efficiency of the heat engine, in which a radical advance is limited by formidable difficulties; but is the recovery of the potential energy of all the fuel, by electric collection.

C. Turbo Induction Generator

Assume then that wherever fuel is burned to produce steam for heating purposes, instead of a low-pressure boiler giving a few pounds over-pressure only, we generate the steam at high-pressure at six atmospheres (90 lb.) or, in larger plants, even at 15 atmospheres (220 lb.) passing the steam through a high-pressure turbine wheel directly connected to an induction generator tied into the electric supply system, and then exhaust the steam at 1.25 atmospheres (19 lb.) into the steam heating system, or at 0.48 atmospheres (7 lb.) into a vacuum heating system.

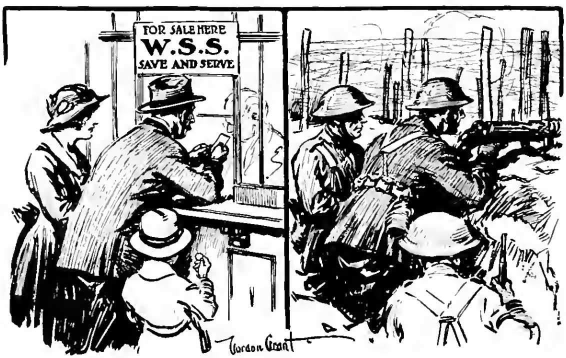
At a fuel value of the coal of 30,000 kj. per kg. we have (see table).

From this it would follow that the average magnitude of the steam turbine induction generator plant for power collection from fuel in heating plants, would be about one quarter to one half kw. per ton of coal burned annually, under the assumption that the use of the heating plant is equivalent to full capacity during one quarter of the time, and the turbine induction generator plant 50 per cent larger, to take care of maximum loads. As seen, the value of the recovered power would be a substantial percentage of the fuel cost.

With 100 million tons of coal used for heating purposes annually, assuming an average recovery of 600 kw-hr. per ton, this gives a total of 60,000 million kw-hr. per year. One quarter of this is more electric power than is now produced at Niagara, Chicago, New York, and a few other of the biggest electric systems together.

Per ton of coal: Chemical energy, 30×10^6 kj.: Heat energy of steam from boiler at 75 per cent boiler efficiency, 22.5×10^6 kj.

	Boiler Press		Dist. Press		Carnot-Efficiency Per Cent	Output at 50 Per Cent Efficiency		Value of Power at ½c. per Kw-hr. $...	Average Kw. Assuming 25% Time of Use	Tons of Coal per Kw.	Size of Induction Generator per 100 Tons Coal Annually
	Atm.	Lb.	Atm.	Lb.		Kj × 1000	Kw-hr.				
Steam Heating	6	90	1.25	19	12.3	1380	385	1.92	0.176	5.7	25 kw.
	15	220	1.25	19	19.8	2230	620	3.10	0.283	3.5	45 kw.
Vacuum Heating	6	90	0.48	7	18.1	2030	565	2.82	0.258	3.9	40 kw.
	15	220	0.48	7	25.0	2820	810	4.05	0.37	2.7	55 kw.



Over the Counter Means Over the Top

Methods for More Efficiently Utilizing Our Fuel Resources

Part XIX. By-Product Coke Ovens

By E. B. Elliott

The Semet-Solvay Company

The purpose of this installment of our series is to show that the production of coke in the bee-hive oven process is wasteful of our fuel resources and that the by-product oven process is efficient. The character and amount of the saving by the by-product process is set forth in the opening paragraphs. The development of the coke oven industry, the construction of the by-product ovens, and the operation of the bee-hive and by-product ovens are described. The power requirements are specified and then the possibilities of fuel savings are treated in detail. The relative cost of energy in fuel is analyzed in the remainder of the article.—Editor

In the first of this series of articles, Mr. I. C. White is quoted as saying:

"If the wasteful methods of the past are to continue to make the sky lurid within sight of the city of Pittsburgh, consuming with frightful speed one third of the power and one half of the values locked up in these priceless supplies of coking coal, the present century will see the termination of the American industrial supremacy in the iron and steel business of the world."

Coke must be produced but the fuel waste which Mr. White condemns will be eliminated by replacing the bee-hive ovens with modern by-product ovens. The approximate net return from coking 2000 pounds of coal in the two types of ovens may be summarized as in Table I.

TABLE I

APPROXIMATE NET RETURN FROM COKING 2000 LB. OF COAL

Return	Bee-Hive Oven	By-product Oven Regenerative Type
Coke, pounds	1250	1500
Steam, pounds	(3000)	
Ammonia, pounds (as Sulphate)		20 to 25
Crude Benzol, gallons		2.5 to 3.5
Tar, gallons		6 to 10
Surplus Gas, M. cu. ft.		4500 to 6500

The figure given for steam produced in waste-heat boilers in a bee-hive plant is nominal, and in most bee-hive plants no steam is

PREVIOUS INSTALLMENTS OF THE SERIES

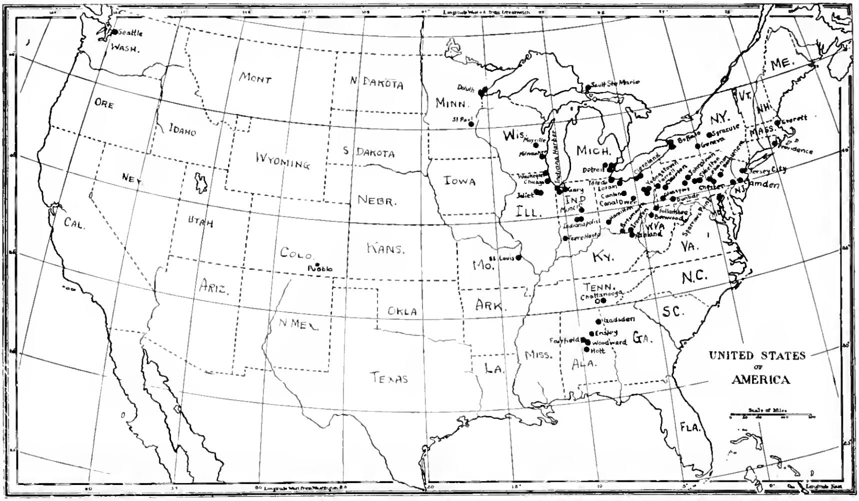


Fig. 1. Map Showing Location of the By-product Coke Oven Plants in the United States. Approximately 11,500 ovens have been erected

recovered. Owing to the fact that all the gas driven off from the coal (as well as some of the coal) is burned, there is a large volume of products of combustion at a high temperature. A proper installation of waste-heat boilers might generate more steam, but, owing to the isolated location of most bee-hive plants, there is little to be gained in generating more steam than is required for local operation. Moreover, the production of steam is not uniform because of the irregularity in charging the ovens.

The chief advantages of the by-product over the bee-hive oven are:

1. The recovery of ammonia and benzol are imperative in war time and it is obvious that maximum production of these items in time of war can be attained only after a period of peace in which their recovery has been profitable.

2. Saving in the nation's fuel resources.
   (a) The yield of coke from a ton of coal is greater.
   (b) Coals that will not coke in a bee-hive oven may be handled satisfactorily in a by-product oven.
   (c) The best blast furnace results are obtained with by-product coke, i.e., for a given iron tonnage less coke is charged into the furnace.
   (d) Recovery of surplus gas, tar, and benzol, all of which may be used as substitutes for natural fuels.

3. The cost of making by-product coke at the blast furnace plant is lower than the cost of bee-hive coke made at the mines and shipped to the plant. The cost of producing a ton of steel is therefore lowered.
   (a) The whole operation is closely connected so that the blast furnace superintendent can obtain the quality of coke best suited to local conditions.
   (b) The surplus gas can be utilized either in the steel plant or may be sold to the nearest municipality.
   (c) The benzol may be used for enriching the surplus gas where there is no better use for it.

Waste in Operation of Bee-hive Ovens

Referring to the curve of production, Fig. 2, and assuming an average coke yield of 62.5 per cent in bee-hive ovens and 72 per cent in by-product ovens, it is estimated that during the past decade the bee-hive ovens coked 485,000,000 tons of coal and the by-product ovens coked 160,000,000 tons, the total quantity of coal coked being estimated at 645,000,000 tons. It is further estimated that the same total amount of coke could have been produced in by-product ovens by coking only 585,000,000 tons of coal. The net loss of the nation's resources, due to the operation of the bee-hive ovens during the period, is therefore estimated at 60,000,000 tons of coal.

In 1917, the total production of coke is estimated at 56,600,000 tons. Of this 34,000,000 tons were produced in bee-hive ovens and 22,600,000 tons were produced in by-product ovens.

Assuming a coke yield of 75 per cent in the modern by-product oven and 62.5 per cent in the present bee-hive ovens, it is estimated that the same total amount of coke could have been produced in the by-product ovens in 1917 with a saving of 9,000,000 tons of coal, which is probably 10 per cent of the coal used in the current year for domestic fuel.

If the 34,000,000 tons of coke that were produced in bee-hive ovens had been produced in modern by-product ovens, there would have been available 750,000,000 cu. ft. of surplus gas *daily*. This would supply 12 cities with the volume of gas now used by the city of Chicago.

If fired under boilers with only moderate economy, it would generate sufficient steam to produce electric power continuously at the rate of 500,000 kw.

If the 34,000,000 tons of coke had been produced in modern by-product coke ovens, it would have been possible to recover 65,000,000 gallons of motor benzel. So far as engine fuel is concerned, with this quantity of benzol on hand, it would be possible to dispatch a train of 600 one-ton motor trucks from Detroit each day throughout the year, each supplied with enough fuel to carry it to the seaboard and return.

At this time when the conservation of food is of general interest, it is in order for us to remind ourselves that ammonium sulphate is frequently the chief constituent in the fertilizer which stimulates the growth of crops. Moreover, the preservation of perishable foods is dependent on refrigeration, and ammonia liquor recovered in by-product coke plants is used by the largest manufacturers in their refrigerating systems.

Development of the Coke Oven Industry

The first bee-hive ovens were built in the Connellsville region in 1841 and this type

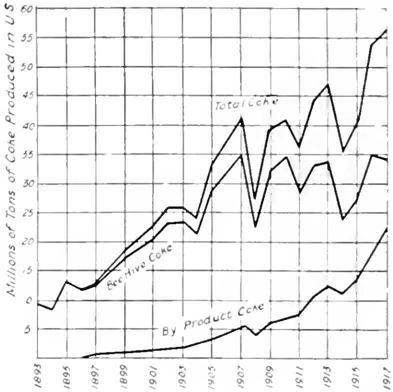


Fig 2. These Curves Show the Total Yearly Production of Coke in the United States; also the Amount Produced in Bee Hive and By-product Coke Ovens. In 1917 the by-product ovens made 45 per cent of the total

reached its greatest development in that district. The first bee-hive coke was made by covering with earth a pile of coal, which is a method similar to that employed in the early days of charcoal manufacture. Later on, round chambers with dome-shaped roofs built of stone and fire brick were used. After a hot charge of coke had been quenched with water in this chamber and drawn out by hand, a fresh charge of coal was dropped in and the air supply was so regulated that the volatile matter (which was driven off by the radiant heat from the walls and roof) was burned and in this way a coking temperature was maintained. In principle this plan is still followed even in the modern rectangular chambers, known as "pushing bee-hives."

Efforts to recover by-products from coal started in Europe in the early eighties. In Germany the industry was developed with the regenerator type of oven, and in Belgium with the recuperator type. The latter lends itself to the cheap production of waste-heat steam whereas the regenerator type should deliver the maximum yield of gas with a com-

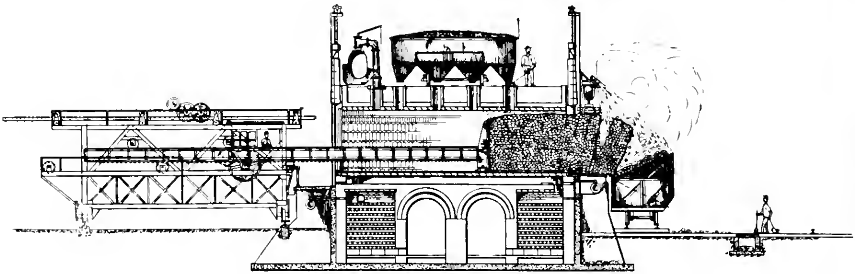


Fig. 3. Conventional Illustration of Coke being Discharged from a By-product Coke Oven
This also shows a longitudinal section of a regenerator type of oven

paratively small yield of waste-heat steam. Naturally, German efforts were along the line of their first success, but there came a time when the lack of a demand for gas and the relative importance of low-cost steam for distillation of by-products caused the Germans to temporarily abandon the regenerator type of oven.

In 1892, the first battery of by-product ovens were built in the United States. They were of the Semet-Solvay recuperator type and were erected at Syracuse, N. Y. Since that time the growth of the industry has been rapid as is shown by the chart of yearly productions, Fig. 2, and the map of plant locations, Fig. 1.

Construction of By-product Ovens

In principle, a by-product oven is simply a closed retort with provision for external heating of the retort and for collecting the volatile matter driven off from the coal in the retort.

In the recuperator type, the gases in the flues flow continuously in one direction, the products of combustion being used to preheat the air necessary for combustion in the oven flues. The waste gas is passed out through a flue or flues around which the incoming air is made to pass. The waste gases from each oven pass into a main flue parallel to the oven block and then through waste-heat boilers to the stack.

Fig. 4. Panoramic View of a Two-block By-product Coke Oven Plant. Several modern plants

In recent years the regenerator type has gained in favor and practically all the ovens now under construction are of this type. The construction of an oven of the regenerator type is illustrated in Fig. 3. There are two main flues and two sections of checker brick. The products of combustion pass out of one set of the checker-brick chambers to one main flue, while the air for the oven flues is drawn in through the other main flue and checker-work chambers. The flow of the gas and air is reversed at frequent intervals (usually every half hour), thus allowing the incoming air to take up the heat absorbed by the checker brick from the waste gas.

Recuperative or regenerative types of ovens may have either horizontal or vertical flues for heating the oven chamber and the gas may pass through the flues either in series or in parallel.

Ovens have been built in batteries or blocks of as many as 120 ovens, although 60 ovens per block is probably near the present average. A view of a modern block of ovens is shown in Fig. 4.

The oven chamber is about 35 to 40 ft. long by 10 to 12 ft. high and 16 to 20 in. wide. The heating flues are on either side of this chamber and are usually built of silica brick.

Fuel gas mains are carried on each side of the oven block. Small manifold pipes branch off this main to the oven flues.

Operation of By-product Ovens

Receiving and Unloading Coal

Coal is brought to the plant by rail or water. Rail coal comes in hopper bottom cars from which it is dumped into track hoppers. It is fed from the track hopper onto a conveyor belt which carries it to the coal preparation plant.

In case the coal is to be stored, the car may either be lifted bodily 50 to 75 ft. from the track by a car dumper and its contents spilled into a hopper or the coal may be dropped from the car directly into a hopper underneath the track. From the hopper the coal may either be dropped into a lorry car and carried to the stocking bridge or it may be carried direct from the track hopper onto the stocking bridge on a belt conveyor. Where a bridge is used strictly for storage purposes, the coal is either fed onto the bridge on a belt conveyor or is dumped into a circular or rectangular receiving pit from which it is lifted by a clam-shell bucket of 4 to 10 tons capacity. The bridge structure usually supports a hopper into which the coal may be dumped, when the bucket is used for reclaiming. The coal is taken from this bridge hopper by a lorry car or belt conveyor.

Coal brought to the plant by Great Lakes' freighters, which have 6000 to 13,000 tons capacity, is usually lifted out of the ship's hold with electrically operated unloading towers. These towers have been built with

ve as many as eight blocks of ovens and the Clairton plant will ultimately have sixteen blocks a maximum capacity of 1000 tons per hour from boat to hopper on the unloader. From the hopper on the unloader the coal is dumped onto a belt conveyor or into lorry cars to be taken to the coal preparation building or to the stocking bridge. Some plants stock two or three hundred thousand tons of coal during the season of navigation on the Lakes.

Coal Preparation

In the coal preparation plant the coal passes through a rough crusher or a bradford breaker where it is reduced in size so that 90 per cent will pass through a 1¼-inch square opening. From the rough crusher the coal is elevated to the mixing bins from whence it is passed through a proportional feeder into the pulverizer or hammer mill. Most plants use a mixture of high and low-volatile coals so that the proportional feeder is necessary to insure the correct percentage of each. The hammer mill grinds the coal to a fineness such that from 60 to 95 per cent of it will pass through a screen with ⅛-inch square openings. This fine coal is elevated and conveyed to the storage bins over the ovens.

Charging the Ovens

After an oven has been pushed the doors at the end of the chamber are closed and sealed with luting clay. The coal is taken from the storage bins, which are located over the oven block, in an electrically operated charging car, Fig. 7, to a point directly over the oven. Twelve to sixteen tons of coal are dumped into the oven, an even distribution being obtained by the horizontal reciprocating motion of a leveling bar. This leveling bar is usually mounted on the pusher, which is illustrated in Fig. 8. This leveling process is necessary in order that the maximum tonnage of coal may be charged into the ovens; it also insures a free passage of the gas out of the oven. After the coal is dropped into the oven, the charging hole covers are closed and the leveling doors at the end of the ovens are closed.

Process of Coking

The coal is sealed in the oven for from 12 to 20 hours (depending on the type and width of oven, the quality of coal charged, and the quality of coke desired) the gas being driven off through the vertical riser into the hydraulic main shown at the upper left-hand corner of Fig. 3.

The gas driven off during the first half of the coking period is richer in illuminants and higher in calorific value; and, where gas is supplied for domestic use, it is the custom to have a double collector pipe on the oven block so that the "rich" gas can be separated from the "lean"—the latter being used to heat the ovens. Where the surplus gas is not sold for domestic purposes, the separation of the gas is usually unnecessary and the surplus gas is then utilized for industrial purposes or, lacking a market, it is burned under boilers in the plant.

Fig. 5. View of Coal Storage Pile at South Chicago. Both steam and electrically operated unloaders and electrically operated stocking bridge are shown. There is sufficient storage area to care for 300,000 tons of coal

The temperature in the oven chamber or retort is maintained by gas burned in the flues on each side of it; a temperature of from 1000 to 1500 deg. C. being carried in these flues.

Exhausting and Scrubbing the Gas

As the gas leaves the oven, it passes through the collector pipe where it is either showered with water and weak ammonia liquor or the pipe may be flushed with tar circulation, to prevent stoppages. The former method throws down considerable tar and ammonia, these being separated by decantation. After leaving the collector pipe, the gas is drawn through a cooler where it is again sprayed with weak liquor and more tar and ammonia are removed. The gas is drawn through this cooler by an exhauster of either the positive or centrifugal type, Fig. 6, a and b. This exhauster assists in the removal of the tar from the gas. The suction on the exhauster is usually about 4 to 8 inches water gage and the discharge pressure is seldom more than 3½ lb., depending upon the scrubbing equipment and the friction in the pipe lines. The temperature of the gas at the exhauster ranges from 25 to 50 deg. C.

The exhauster forces the gas through an ammonia scrubber of the counter-current type. Here the last of the ammonia is taken out and the gas then passes through a benzol scrubber where it is sprayed with heavy oil instead of water or weak liquor. It is then ready for commercial distribution without further treatment, except when it is to be used for domestic purposes in which case it is purified from sulphur in purifiers of the type common in other gas manufacturing plants.

Ammonia liquor and tar, recovered from the circulation systems mentioned, are collected into large decanters and separated by their specific gravities. The moisture in the tar is driven off by heat and the tar is then ready for shipment to the refiner.

The ammonia is driven off from the weak liquor containing 1½ to 2 per cent of ammonia by heat in the still. The fixed ammonia (carbonate, chloride, etc.) is set free by treatment with lime. The ammonia vapor is absorbed in water and the product, containing some impurities, is the crude ammonia liquor of commerce.

The crude benzol is recovered from the absorbing oil by distillation, the absorbing oil being again returned to the scrubber.

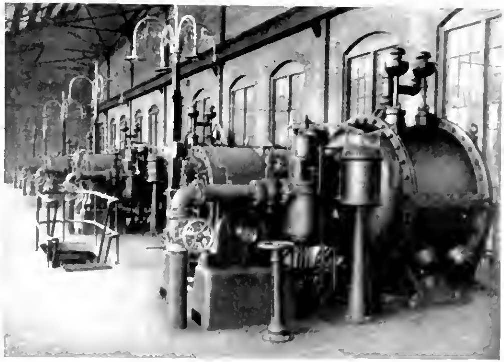


Fig. 6, a and b. General Electric Turbine driven Centrifugal Exhausters. These units are used to draw the gas through the primary coolers and force it through the ammonia and crude benzol scrubbers

Quenching the Coke

After practically all the gas has been driven out of the coal in the retort, the doors are opened and the coke resulting is pushed out into a quenching car by an electrically operated ram. This operation is illustrated in Fig. 3. The pusher is shown in Fig. 8.

The quenching car is 40 to 50 ft. long and 10 ft. wide, and has a sloping bottom. This car is usually drawn by an electric locomotive as shown in Figs. 9 and 10. While the coke is being pushed the car is traversed in a direction parallel to the oven block at a speed of about 60 ft. per minute so that the coke is distributed uniformly throughout its length. As soon as all the coke from the oven has been pushed into the car, the locomotive draws it rapidly to the quenching station where the red hot coke is showered with water. Enough water is applied to promptly cool the outside of the coke and prevent combustion, but leaving enough heat in the center of the piece to drive off the excess water and so produce dry coke. The quenching car then dumps the coke into a hopper from which it is fed onto a belt or pan conveyor and is carried to the coke screening plant. In the coke handling plant the coke as it comes from the oven is crushed and screened so that the various sizes may be produced uniformly.

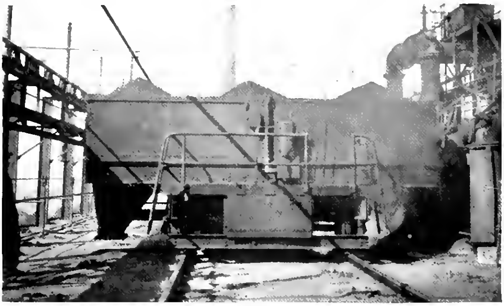


Fig. 7. A Charging Car in Position for Discharging its Load of Coal Into an Oven

Power Requirements

If there were extensive coal handling machinery and all moving equipment were motor driven, the demand for electricity might reach 15 kw-hr. per ton of coal coked. The demand for exhaust steam in the by-product recovery, however, is usually such that the exhausters, fans, and some pumps are steam driven and the electric power consumption therefore seldom averages over 10 kw-hr. per ton. Some partially electrified plants use only 3 or 4 kw-hr. per ton.

The operation of the plant is necessarily continuous, and since roughly 50 per cent of the electrical load is made up of pumps in by-product recovery work the load-factor is usually high.

Possibilities of Fuel Saving

Broadly speaking, coal can be saved in three ways:

1. More efficient combustion.
2. More efficient use of heat.
3. Substitution of by-products for coal.

The following is a brief discussion of the second and third methods as applied to by-product ovens:

Waste-Heat Steam

During the period in which the demand for cheap steam for distillation and the lack

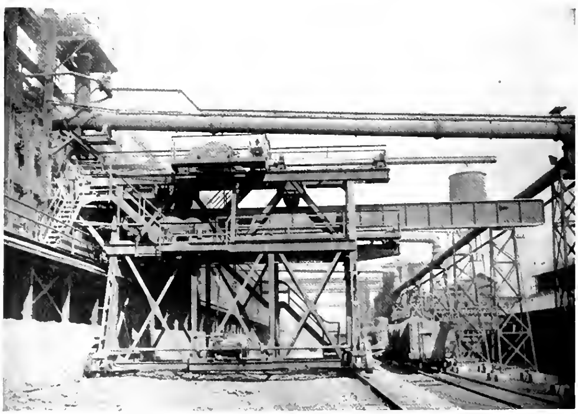


Fig. 8. A Coke Pusher. This plant is located on the Ohio River and is built on high foundations to avoid damage from floods. This accounts for the height of the structural supports under the real operative part of the pusher

of demand for gas favored the commercial development of the recuperator type of oven, a large number of such plants were placed in successful operation in the United States. Waste-heat boilers were considered a part of the plant; two boilers set in one battery were usually connected to each oven block and the waste gases passed through these boilers in parallel.

To get the maximum production out of waste-heat boilers, it is necessary to maintain a low temperature in the gases leaving the boiler and to prevent air leakage into the flues ahead of the boiler as well as in the setting. The boiler should be so designed and baffled that the gases will be drawn through it at a high velocity.

Good modern operating practice will develop 100 per cent of boiler rating, the

Fig. 9. This View Shows the Red Hot Coke being Discharged from an Oven into the Quenching Car

gases coming to the boiler at 700 to 800 deg. C. and leaving at 200 to 300 deg. C.

Use of Coke-oven Gas

In some sections where the gas has no better market, it has been used as boiler fuel. Coke-oven gas without separation should average 550 B.t.u. per cu. ft. and an over-all efficiency of 75 per cent should be readily attainable. On this basis, 2350 cu. ft. of gas is required to evaporate 1000 pounds of water. However, most coke-oven plants either sell their surplus gas for illuminating

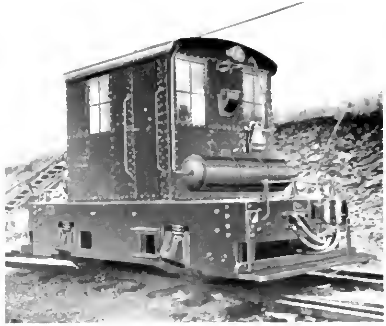


Fig. 10. A 20-ton Electrically Operated Quenching Car Locomotive

purposes or dispose of it in the adjoining industries. Coke-oven gas is a perfected fuel in the sense that it may be piped to any place where heat is needed and may be used efficiently in all applications. For this reason the gas should be used in industrial heating furnaces rather than under boilers, because a perfected fuel should not compete with a raw fuel where the raw fuel is used so efficiently as in present boiler furnaces. It has been found that the production of an open-hearth steel furnace is from 10 to 15 per cent greater when using coke-oven gas or coke-oven gas and tar, than when using producer gas.

The economy of coke oven gas in large gas engines has been demonstrated at some of our modern steel plants. Moderate sized engines have been built which develop a brake h.p.-hr. on 20 cu. ft. of 550 B.t.u. gas. More of these engines may be put in service as the cost of coal increases.

Use of Breeze

No definite standard has been established covering the sizing of breeze. In a paper read before the Illinois Gas Association, March 2[illegible], 1912, Mr. C. J. Ba[illegible], classifies as breeze that portion of the product that passes over a ½-inch screen and through a ¾-inch screen; the portion that passes through the ½-inch screen being called coke dust. Others consider that the portion passing through the ½-inch screen is breeze, the larger sizes being designated as pea coke.

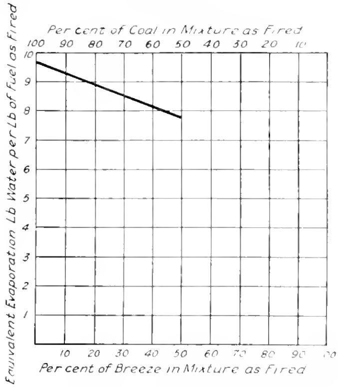


Fig. 11. Curve Showing the Evaporation for Various Percentages of Breeze in a Breeze-coal Mixture

The lack of uniformity in the sizing of breeze is indicated in Table II.

TABLE II

SCREENING VARIATION IN TWO SAMPLES OF BREEZE

Sample	A	B
Over $\frac{9}{16}$-in. screen	33.6 per cent	5.1 per cent
Over ⅜-in. screen	24.1 per cent	5.5 per cent
Over $\frac{3}{16}$-in. screen	13.3 per cent	16.9 per cent
Over $\frac{3}{32}$-in. screen	12.3 per cent	19.3 per cent
Through $\frac{3}{32}$-in. screen	16.7 per cent	53.2 per cent

Sample *A* might be considered as about average. Sample *B* is from a product out of which the pea coke has been screened for use as domestic fuel. In plants where the main object is to supply fuel to a blast furnace, much larger pieces of coke than shown in sample *A* are allowed to go through as breeze.

The analysis of this breeze is given in Table III.

TABLE III

FUEL ANALYSIS OF BREEZE

Test Number	1	2
Volatile	4.1 per cent	4.3 per cent
Fixed Carbon..... .	74.1 per cent	69.2 per cent
Ash..... ...	21.8 per cent	26.5 per cent

The differences in quality and in sizing account for the divergence in reports on the value of breeze burned under boilers. A report which does not include average screening tests as well as an analysis is apt to be misleading.

In producing blast furnace coke about 4 per cent of the total coke production is classified as breeze or coke dust, but this percentage varies with the amount of coke preparation required.

To successfully burn breeze under a boiler, the fire must be handled with more care than is required in burning good steam coal. Breeze is usually charged to the boiler house at a comparatively low price and with proper firing cheap steam can be produced. Shaking grates have been successfully used although some engineers prefer stationary grates. The ratio of air space to total grate area should be from 30 to 40 per cent. The pressure in the ash pit should be from ¾ to 2 inches water gage depending on the size and shape of the grate openings. There should be more air space on the bottom surface of the grates than on the top surface as this will prevent the ash from wedging in the openings.

The average breeze will have a heating value of 10,000 to 11,000 B.t.u. per pound and is worth 60 to 80 per cent of its weight in good soft coal. The boilers can be operated at from 100 to 125 per cent of their rating.

In 1914, a number of tests were made using the breeze from which samples in Table III were taken. This breeze was intimately mixed with Dixonville coal and the mixture was burned under a 240 h.p., B & W boiler, an underfeed stoker being used. Mixtures containing 12½, 25, and 50 per cent of breeze were tried. The average evaporative value of the mixture, as compared with straight Dixonville coal, is shown on the curve in Fig. 11. Tests were also made with straight breeze on the stoker, and the broad conclusions reached were as follows:

1. Breeze-coal mixtures containing up to 50 per cent of breeze can be burned on an underfeed stoker, in an ordinary soft coal furnace, with a steam generation of 100 per cent or more of boiler rating.

2. Because of the tendency for clinkers to give trouble with higher percentages of breeze, it is believed that the best results will be obtained from mixtures containing up to 25 per cent of breeze.

3. The price of breeze should be based on its calorific value as compared with the

calorific value of the fuel with which it competes, minus a fair figure for additional cost of handling ashes and removing dust from combustion chambers, which should seldom, if ever, exceed 5 cents per ton.

The type of stoker must be carefully selected, especially when larger percentages of breeze are used. The best results can be obtained with this fuel only when special attention is given to its utilization. The same thing has been demonstrated in hand firing.

Recently some successful installations of chain-grate stokers have been made. Two important ideas have been utilized in the adaptation of this type of stoker to burning breeze.

1. A high-temperature arch to kindle the fire quickly. Fire does not spread rapidly in coke dust and some means of igniting it promptly at the entrance to the furnace is essential.

2. Control of the distribution of the air under the fuel bed.

Use of Coal Tar

Crude coal tar has been worked up into some two thousand products although many of these compounds have been produced only in laboratories.

Coal tar contains the bases of many products which are used in the dye and color industry now developing in this country.

The phrase "coal tar dyes" originated because the only source for the raw materials for the early dyes was crude benzol obtained by distilling coal tar. The amount of crude benzol now obtained by scrubbing all the coal gas is about nineteen times as much as is obtained by refining coal tar.

The important industry of wood preserving is dependent upon the production of coal tar. Most of the large railroad companies prolong the life of wood ties by treatment with creosote oil and many public utilities protect their wood transmission and telephone poles in the same way. Since wood is a fuel, it is clear that the Nation's fuel resources are conserved indirectly by this use of tar.

Pitch recovered from coal tar is used extensively in the manufacture of roofing compounds, which are used as a substitute for wood shingles. These indirect methods of saving our fuel resources, while relatively unimportant, are mentioned to emphasize the far-reaching effect of the coking of coal in by-product coke ovens.

In the Bureau of Mines Technical Paper 37, I. C. Allen says that while coke-oven tar burns readily in heavy oil engines there is a possibility of carbon deposit in the cylinder which can best be forestalled by distillation of the tar. It is possible that considerable tar may be used in the future in this way.

Quantities of tar have been burned under boilers. Early experimenters with this fuel

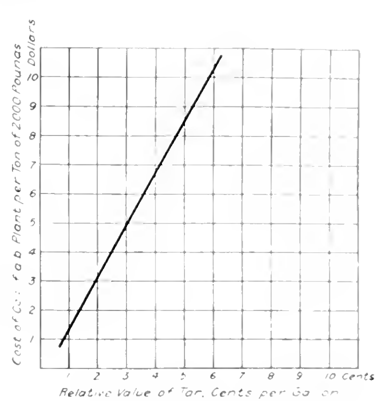


Fig. 12. Curve Showing Approximately the Heating Value of Tar as a Boiler Fuel

experienced the same difficulty reported by advocates of pulverized coal; viz. the intense flame destroyed furnace linings and even burned out tubes where the flame was concentrated. These troubles were overcome by using burners that diffused the flame, and in some cases, by using silica brick linings.

The curve in Fig. 12 shows the approximate heat value of tar compared with coal at various prices per ton. In making up this curve, it was assumed that the tar would be used in a modern boiler house equipped with coal and ash handling systems. This is done to show the possibility of using tar in an existing boiler house. If it is assumed that the boiler house is equipped for handling tar only, a considerable saving in fixed charges could be credited to tar as a fuel. The curve is based on the assumption that to the cost of the coal, as shown by the ordinates, there would be added a charge of 35 cents per ton for coal and ash handling.

Table IV shows approximately the heating value that may be bought for one dollar in various solid, gaseous, and liquid fuels at given prices; and it may be found convenient as a ready reference.

RELATIVE COST OF ENERGY IN FUELS

Tar is now used successfully in heating metallurgical furnaces. One of the large steel companies uses its large production of coal tar for this purpose and has found that tar has a value equivalent to petroleum fuel oil.

Benzol

At the outbreak of the European War, fourteen crude benzol plants were in operation in connection with by-product coke-oven plants. In 1913, these plants recovered about seven million gallons, nearly 80 per cent of which was used for the enrichment of gas.

At that time, Germany was recovering thirty million gallons of benzol. Since the outbreak of the War, accurate figures on German production have not been available but no doubt the output has been enormously increased. In 1914, when Germany was advancing on Liege, a squad of technical men was sent on with the army to take charge of the coke-oven plant at the Cockerel Works. Whatever may have been the German official instructions in connection with cathedrals, there has been no report of German artillery shelling by-product coke-oven plants unnecessarily.

Early in the war, the Italian Government made the washing of all coal gas for benzol compulsory. Large plants were required to put in recovery equipment at their own expense, smaller plants were aided by a subsidy. The government permitted a reduction of the heating value of the gas to 517 B.t.u. per cu. ft.

In England the gas industry was mobilized, standardized recovery equipment being installed in all plants. The total production has increased about sixfold.

Practically all the new by-product coke-oven plants recently built in the United States have benzol recovery plants. Arrangements for the recovery of benzol have also been made by many of the large gas companies so that when the war is over there is reason to believe that the American capacity for benzol production will exceed that of Germany.

TABLE IV
RELATIVE COST OF ENERGY IN FUELS

Kind	Cost	B.t.u.	Number of B.t.u. Bought for $1
Small Anthracite	$2.50 per ton	12,500 per lb.	10,000,000
Large Anthracite	6.25 per ton	14,000 per lb.	4,500,000
Bituminous Coal	3.00 per net ton	13,500 per lb.	9,000,000
Coke Breeze (wet)	1.00 per net ton	10,000 per lb.	20,000,000
Illuminating Gas	1.00 per M. cu. ft.	550 per cu. ft.	550,000
Natural Gas	.20 per M. cu. ft.	1,000 per cu. ft.	5,000,000
Coke Oven Gas	.10 per M. cu. ft.	550 per cu. ft.	5,500,000
Coke Oven Gas	.15 per M. cu. ft.	550 per cu. ft.	3,650,000
Coke Oven Gas	.20 per M. cu. ft.	550 per cu. ft.	2,750,000
Producer Gas	.03 per M. cu. ft.	150 per cu. ft.	5,000,000
Crude Oil	.04 per gallon	20,000 per lb.	3,650,000
Kerosene	.10 per gallon	20,000 per lb.	1,200,000
Kerosene	.30 per gallon	20,000 per lb.	400,000
Gasolene	.10 per gallon	20,000 per lb.	1,200,000
Gasolene	.30 per gallon	20,000 per lb.	400,000
Grain Alcohol	.30 per gallon	12,000 per lb.	270,000
Grain Alcohol	.40 per gallon	12,000 per lb.	200,000
Coal Tar	.02 per gallon	16,000 per lb.	8,000,000

These increases in production in European countries were made because of the demand for munitions. In America, the increase was possible because it was easy for all to see the importance of the rapid development of this industry, and because the financial situation was favorable to promotion.

After the war, it is probable that a good portion of the crude benzol produced will be available as automobile engine fuel. Its value for this service has been thoroughly demonstrated. A mixture of gasolene and benzol in equal parts will give 20 to 25 per cent more mileage than straight gasolene. Due to the slower rate of combustion of benzol or benzol-gasolene mixtures, the initial pressure in the cylinder is lower than where pure gasolene is used, but the pressure is maintained over a greater portion of the stroke. This makes an indicator card that looks more like a card from a steam engine. The steadier pressure in the cylinder enables the engine to carry heavier loads at slow speeds without the knocking that is noticed on hill climbing where straight gasolene is used. Some authorities believe that the greatest help in this direction will come from the mixture of benzol with denatured alcohol. The latter will not work successfully alone nor will it mix with gasolene, but satisfactory results have been attained with benzol-alcohol mixtures.

In the past, where surplus gas has been sold to municipalities it has frequently been the practice to vaporize into the gas from 0.1 to 0.4 gallons of crude benzol per M cu. ft of gas for enrichment. This was done to make the gas meet the municipal requirements as to candle-power. Originally, there was merit in this requirement because so much illuminating gas was used in open-jet burners. The well-nigh universal use of mantles has removed the desirability of the candle-power clause in municipal specifications. The consumer is interested only in the heating value of the gas. Except in some municipalities, the United States has practically adopted the calorific standard instead of the candle-power standard for domestic gas; and a volume of oil has thus been released for more important uses. The requirements of the war are assisting greatly in effecting this important economic reform. Because of the great need for light oil derivatives for munitions, the waiving of this clause can well be pressed at this time. In peace times, the oil so released could be used to much better advantage in automobiles, thus relieving the natural oil situation somewhat.

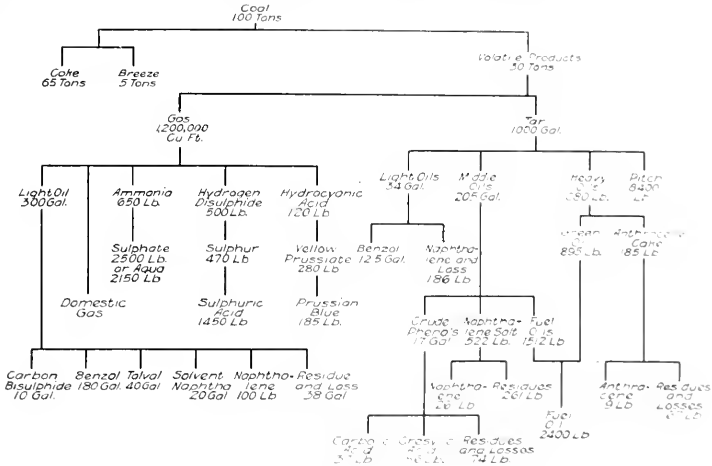


Fig. 13. Chart showing By-products Resulting from Distillation of 100 Tons of Coal in the Manufacture of Coke, and the Various Substances that may be Derived from Them

Coke for House Heating

All sizes of coke down to pea coke are suitable for house heating although the fire box in a good many furnaces is too small to properly handle the larger sizes. Coke is the only logical substitute for anthracite. Owing to the greater bulk of coke it is also handicapped somewhat in the eyes of the householder, because it takes up more space in the bin and because there is more shoveling required. Coke is a cleaner fuel than coal and ton for ton will produce as much heat as anthracite. Of course, coke quality varies with the quality of the bituminous coal from which it is made just as the quality of anthracite varies. The quality of anthracite seems to be gradually decreasing whereas the quality of coke grows better as more is learned about its manufacture. With this in mind it is not difficult to imagine coke entirely taking the place of anthracite, at least at points remote from the mines.

Conclusion

In 1881, Sir William Siemens said:

"I am bold enough to go so far as to say that raw coal should not be used for any purpose whatsoever, and that the first step toward the judicious and economical production of heat is the gas retort or gas producer, in which the coal is converted into gas, or gas and coke, as is the case at our ordinary gas works."

A study of the curve of coke production and the map, Fig. 1, showing the location of by-product coke-oven plants in the United States will show that the development has been rapid. For the duration of the war, it is probable that it will be impossible to meet the demand for by-products. It is to be hoped that the war will be over before some of the plants now under construction are completed. In any event, when peace does come, we will be confronted with the problem of utilizing most advantageously the by-products that will result from a normal production of coke.

By summarizing the fuel values recovered in by-product ovens, we can satisfy ourselves that at least 25 per cent of the fuel value of the coal coked in bee-hive ovens is wasted. If we are to promptly secure the great saving in national resources that inevitably results from the widespread use of by-product ovens, it will be the mission of the chemist to develop the processes for manufacturing the refined coal-tar products, and it will be the duty of the power engineer to economically utilize the by-product fuels in the production of heat and power.

A WAR RESOLUTION ADOPTED BY NATIONAL ELECTRIC LIGHT ASSOCIATION, JUNE 13, 1918

"*Resolved*, That the National Electric Light Association in annual convention assembled, desires to extend to the President of the United States and all others in the authority the assurance that in its organization and its membership it is in thorough accord with the fixed determination of the American people and their chosen representatives to prosecute the war with the utmost vigor and to a victorious conclusion—however long it may take and however much it may cost in men, money, and other forms of sacrifice.

"The goal we seek through the prosecution of the war is the winning of a great peace—a peace so well established that it cannot lightly be disturbed by autocratic force wedded to the doctrine that might makes right. For such an end of the war we are ready cheerfully to submit to such further restrictions of personal and corporate activities and to such further burdens upon private and corporate property and business, as may be found necessary to impose upon the people and industries of the country.

"We recognize as the one great menace of the future the possibility of an inconclusive peace—an armed truce which would inevitably end in a renewal of the unspeakable horrors of the present war. That must not be, and the only way to prevent it is to carry this war to VICTORY—a victory so complete and overwhelming that the forces of evil will be glad to accept such terms as an outraged world may be willing in justice to accord. No compromise, no halfway measures, no patched-up "scraps of paper" can accomplish this great end; but only the devotion, the patience, the self-sacrifice, and the undying patriotism of our people and their great Allies.

"With a realizing sense of the stupendous sacrifices involved, but with an abiding faith in the ultimate result, we pledge all that we have and all that we are to the Holy Cause."

A Self-adjusting Spring Thrust Bearing*

By H. G. Reist

Alternating-current Engineering Department, General Electric Company

The opening paragraphs of the article below are devoted to a general dissertation on bearing design, especial attention being given to those features which result in satisfactory operating condition or in dangerous conditions which are liable to produce failure. The construction and operation of the self-adjusting thrust bearing are then described in detail. The principles embodied in the design of this thrust bearing are applicable also to journal bearings and to bearings having a reciprocating motion.—Editor.

It has been shown that the pressure on the babbitted surface of an ordinary journal bearing varies greatly in different parts of the circumference of the bearing, being greater at the center line of the resultant load than toward the sides, and varying approximately inversely with the thickness of the oil film. Whether the greater part of this variation in pressure is due to the difference in thickness of the film, or to the dragging of the oil by the shaft to a point from which it cannot readily escape, is difficult to determine. Apparently the thickness of the film depends on the load per unit area, the viscosity of the oil, and the surface speed of the shaft. Several investigators have shown that with ordinary loads, one hundred pounds average pressure per square inch, the thickness of the oil film at the bottom of the bearing is about two ten-thousandths to three ten-thousandths of an inch. With this in mind, it will readily be understood why the surfaces of the bearing have to be fitted closely to the shaft, why the supporting shell must be made rigid, and, finally, why a soft metal, which may conform to the shaft, is much better for a bearing surface than a hard one. In spite of all the care that may be taken, only a small part of the surface usually fits the shaft to within the foregoing dimensions; and the load is borne on a restricted area with a pressure many times the average and often many times the pressure of that at the bottom of a perfectly fitting bearing. On large bearings it is difficult to prevent the metals from touching, and at starting a small part sometimes takes sufficient load to cause wiping of the babbitt. "Wiping the babbitt" tends to fit the bearing to the shaft under the loaded condition, and may occur only at starting; and not repeat the process afterwards due to a larger bearing surface thus being established. It is better to avoid wiping if possible, as the particles of loosened babbitt metal may injure or destroy the good part of the bearing surface, and there is also danger of scoring the shaft.

In the absence of dirt or grit, bearing failures are due to the squeezing out of the oil film. The pressure necessary to accomplish this is much greater than is generally known. In one case, a pressure of five thousand pounds per square inch was carried for several hours and the babbitted surface was absolutely free from damage. In another case, a pressure of two thousand pounds per square inch at a rubbing speed of forty-five hundred feet per minute was successfully carried. The consideration of such experience led to the conclusion that damage to properly lubricated bearings was due to failure of the oil film on so small a part of the total surface that the unit pressures on these surfaces exceeded the values just mentioned.

In order to maintain a film of oil of fairly uniform thickness in bearings of the constructions now in use, it is necessary that the parts which form the bearing surface be exceedingly rigid so that the deflection of the bearing surface will be very small. With this precaution and with very accurate fitting, it is theoretically possible to maintain over the whole surface of the bearing, or over a large area of it, a film of oil sufficiently thin to support a fair pressure per inch of bearing. It is for this reason that the shells of ordinary bearings are made rather stiff so that they will give some support even at their ends. The ideal condition would be to have the deflection of the bearing and shaft the same, but in practice this cannot be accomplished.

The bearing about to be described departs altogether from the principles just mentioned. It is based on the idea of a bearing surface which is so yielding, flexible, and elastic that it can follow the irregularities of the rotating surface without creating at any point a pressure per square inch sufficient to destroy the oil film.

Many of the problems found in the construction of journal bearings are encountered

* Read as a paper before the American Society of Mechanical Engineers, Worcester, Mass., June, 1918.

in the design of thrust bearings. Small bearings, up to perhaps ten inches in diameter, may be readily fitted so that at ordinary speeds the surfaces are sufficiently accurate to form an oil film thin enough to support the load without danger of dragging the babbitt. The parts must be made quite rigid and the seat is usually supported on a spherical surface to correct for slight inaccuracies of alignment.

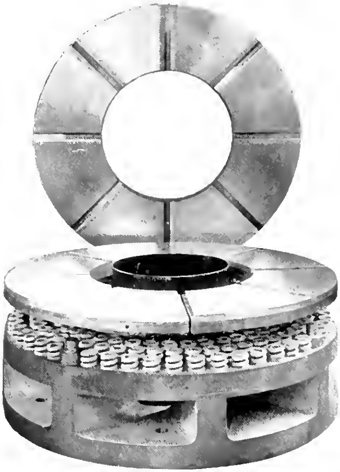


Fig. 1. Spring Thrust Bearing for Vertical Waterwheel Driven Generator to carry a load of 300,000 lb. at 100 r.p.m. showing rubbing surface of rotating ring. Stationary ring is raised to show the arrangement of springs.

Thrust bearings for supporting the heavy loads of water wheels and the electric generators driven by them are now very widely used. The difficulties in the fitting and use of plate bearings are much aggravated as the load is increased, on account of the large over-all dimensions of the supporting plate. It is true that the surfaces can be fitted quite accurately by machine, but there have been cases where the surfaces were turned slightly conical with the result that they bore hard on the inner or the outer edge. The deflection of the supporting collar on the shaft may allow the runner to be slightly dished, or there may be a deflection of the supporting surface, thereby dishing the babbitted seat or causing one side to be lower than the other. The self-adjusting spherical seat, provided to correct some of these difficulties, is of doubtful value on large bearings on account of the great frictional resistance which must be overcome to make it shift.

Thrust-bearing surfaces are usually scraped to each other, or to a surface plate, to avoid dangerously high spots; but, since the oil film is of the order of two ten-thousandths to three ten-thousandths of an inch in thickness, the difference in level must be smaller than these values. This work must usually be done without load and, no matter how carefully it is done, when the bearing is loaded the parts probably will not fit each other, because of deflection.

A careful study of the above difficulties led to the design of a flexible bearing surface pressed against the runner by springs. It seemed that this would prevent the possibility of undue pressure at any point and compel each element of the surface to carry its share of the load. On trial, this solution proved satisfactory.

A typical design of a spring thrust bearing for vertical shaft machines is shown in Fig. 1. The bearing consists of a runner of a special grade of cast iron resting on a thin steel ring which has a babbitted surface. The babbitted stationary ring, in turn, rests on short helical springs and is held against rotation by dowel pins. A saw-cut through one side eliminates any tendency of the ring to "dish" with a change in temperature. The high base-ring shown, on which the springs stand, is often used

Fig. 2. Spring Thrust Bearing with "Compressed Springs" for machines having small clearances. Stationary babbitted ring is raised to show springs and dowel pin.

in connection with a deep housing to increase the amount of oil in the surrounding bath. The tube in the center forms an oil retaining wall around the shaft. The springs ordinarily used are wound of one-half inch round wire, have an outside diameter of two inches, and a free length of one and one-half inches. Under load, the springs close about one-sixteenth of an inch, and the total pressure is well distributed. By this means it is possible to avoid excessive pressures at any point. Thus, it is safe to run with a much higher average pressure than when there is no definite limit to the pressure which may occur over a small area.

It will be seen that this type of bearing differs from the solid ring thrust bearing in that one of the bearing surfaces is made to yield at any point by using a comparatively thin plate supported by a large number of springs. While solid bearings may be used successfully for small loads, a bearing which thus automatically adjusts itself to faults in finish and in alignment is preferable for carrying very heavy weights.

Oil grooves are provided in one of the members and sometimes in both. In order to insure proper circulation of the oil for cooling purposes in the case of bearings operating at low speed, it is necessary to have grooves in the rotor. On high speeds these grooves may sometimes be omitted, and, in such cases, only the friction of the rotor on the oil while passing the grooves in the stator is relied upon for circulation. In many cases, very satisfactory results have been obtained by placing radial grooves in both the rotating and the stationary surface. The usual practice is to have different numbers of grooves in the two plates, for instance, six and eight. With grooves in each of the surfaces, there is a continuous flooding of oil on all the bearing surfaces and a very effective means of cooling. Much of the heat would otherwise have to be transmitted through the metal of the stationary part of the bearing.

The pressure usually allowed on these bearings is from three hundred to four hundred pounds per square inch, the design permitting a very thin oil film without metallic contact. It is necessary to have the runner very smooth and free from scratches, especially any at an angle to the direction of rotation as these might cause injury to the babbitt. The babbitted surface does not need to be scraped, but it is turned with a tool as smooth as is convenient. Wearing sometimes occurs in minute spots all over the plates. When this happens, there is no risk of dragging the metal. The bright spots that appear are produced while starting and slowing down before a pressure film is formed. When in operation, the weight is apparently supported entirely on the oil film.

It is desirable to run bearings at as high a pressure as is safe, for the parts are smaller, the rubbing speed is less, and the friction is very much reduced. With this design of bearing, the tendency to excessive pressure at one point is automatically relieved by the yielding of the springs; and, while there will be some uneven distribution, a variation in pressure of two or three times the average is comparatively unimportant and does not cause bearing failures. It is the pressure of twenty or more times the average that causes injury; these excessive pressures are prevented by the construction just described. For this reason, it is safer to operate this bearing with high pressure than a more rigid bearing at lower pressure.

The loss of alignment, due to settling of foundations or other causes, does not affect the bearing adversely. In one water-wheel driven alternator installation, the striking of the field against the armature led to the discovery that the coupling between the two units had loosened and had allowed the shaft to "run out." The bearing operated without injury with over three-hundredths of an inch vertical movement of the outer edge of the rubbing surface. This caused an uneven distribution of load on the bearing to the extent of reducing the load on one side of the bearing about sixteen per cent and increasing the pressure a simiar percentage on the extreme opposite side.

An advantage of increased pressure in the reduction of friction is shown below.

Bearing	A	B
Revolutions per minute	200	200
Load, total pounds	300,000	300,000
Outside diameter bearing in inches	35	46
Inside diameter bearing in inches	17.5	17.5
Net area [illegible]	600	1200
Pounds per square inch	500	250
Average rubbing speed [illegible]	[illegible]	[illegible]
C[illegible]	[illegible]	[illegible]
Kilowatt[illegible]	[illegible]	[illegible]
Horse[illegible]	[illegible]	[illegible]

In some designs the vertical distance between the water wheel and the casing is very small so that the displacement caused by a free spring under the variation of load is objectionable. In such cases an initial compression equal to full load, or to an overload, is put on the springs. The load will still distribute since an overload at any point will cause the spring to close beyond the initial compression. Such a bearing is shown in Fig. 2. However, this bearing was designed to replace a roller bearing and was so made that the parts of the water wheel would occupy the same relative positions as before. The principles used in the construction of these thrust bearings are applicable also to journal bearings and to bearing surfaces having a reciprocating motion, like the crosshead of a steam or gas engine.

Fundamentals of Illumination Design

PART III. REFLECTORS AND ENCLOSING GLASSWARE

By WARD HARRISON

NATIONAL LAMP WORKS, GENERAL ELECTRIC COMPANY

The two preceding installments of this series dealt, first, with some of the fundamental concepts of the science of illumination, and second, with some of the factors which enter into illumination design, such as diffusion of light, choice of lighting system and intensity, and the proper arrangement of the light sources. Illumination from a given light source can be greatly improved and made to fulfill the requirements of special service through the employment of reflecting or diffusing mediums. For instance, for general office and store lighting the semi-indirect or totally indirect reflectors give a very soft and pleasing light without glare and harsh shadows; while in the automobile head lamp the rays are re-directed by the reflecting surface into practically parallel paths, giving intense illumination over a small area. The properties of some of the various materials employed for reflectors or diffusers are described in this installment.—EDITOR.

The light from a bare incandescent lamp is distributed in a manner such that under most conditions it cannot be employed effectively without the use of reflectors or enclosing glassware. Such accessories should not only redirect into useful angles light which would otherwise be ineffective, but should serve the additional purposes of modifying the brilliancy of the light source and diffusing the light to produce a soft and pleasing illumination.

Three systems of lighting are commonly employed. They have been referred to as direct, indirect, and semi-indirect. In the so-called direct-lighting system, the unit distributes the light downward into the room; in the indirect system all of the light is thrown upon the ceiling and thence reflected into the room; in the semi-indirect system, a greater part of the light is thrown upon the ceiling but some of it passes through the bowl and directly into the room.

In the units for these systems various reflecting surfaces and transmitting media are used, and a knowledge of the action of such surfaces and media in the utilization of light is necessary to a proper selection.

A ray of light unless meeting interference will travel along a straight line indefinitely. Such interference may be in the nature of absorption by the medium through which it passes or by the object upon which it impinges. This is noticed when a beam of light passes through the smoky atmosphere, through a piece of smoked glass, or meets a black opaque body. In these cases, a part or practically all of the light loses its identity and is converted into heat. A second form of interference is termed refraction. Refraction is a bending of the ray of light due to its passing from one medium to another of greater or less density, as, for example, from air to water or from air to glass. A very common instance of refraction is the apparent bending of a fish line at the point where it enters the water; as a matter of fact, the line is straight but the light rays coming from that part of the line which is under the water

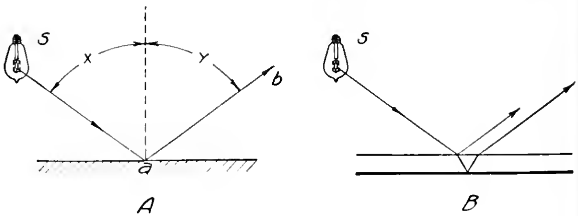


Fig. 1
A—Reflection from Polished Surface
B—Reflection from Mirrored Surface

are refracted when they pass from water into air. A third form of interference with the progress of a ray of light in a straight line is reflection, which is the throwing back or redirection of the ray by a surface. A fourth form of interference is diffusion, which is the breaking up of the beam and spreading of its rays in all directions by the medium through which it passes or by the surface upon which it falls. By controlling these four methods of interference—absorption, refraction, reflection, and diffusion, we are able to make the light from any source do very largely as we desire.

Polished-metal and Mirrored-glass Reflectors

The simplest form of reflection is that which takes place when a ray of light strikes a polished-metal surface. As indicated in sketch A, Fig. 1, a ray of light having a direction *Sa* on striking a polished-metal surface is reflected off in the direction *ab*, so that the angle *Y* (called the angle of reflection) is equal to the angle *X* (called the angle of incidence) and practically no light is reflected in other directions. This is called regular reflection. It will be seen, therefore, that it is possible to redirect light traveling in a given direction into any other desired direction by means of such a surface properly placed. When we consider that the schoolboy by means of a pocket mirror or piece of polished metal can take the beam of sunlight that comes in at the window and redirect it with remarkable accuracy to any place in the room, the general principle involved is seen to be simple. While all polished-metal surfaces reflect light in the manner described, they do not reflect it in like amounts. For instance, if two beams of 100 lumens each fall respectively on a polished-silver surface and on a polished-aluminum surface, the silver will reflect approximately 88 lumens and the aluminum about 62 lumens. In other words, the silver surface will absorb only 12 per cent of the light while the aluminum surface will absorb about 38 per cent. All of the light falling on an opaque surface is either reflected or absorbed by that surface.

Similar to the reflection characteristics of polished metal are those of mirrored glass. Fig. 1, B, shows the path of a ray of light striking the surface of a commercial type of mirror with silvering on the back of the glass. A small part of the light is at once reflected by the polished surface of the glass without passing through to the silvered backing; the remainder passes through the glass to the silver, from which it is reflected through the glass again and out along a line parallel to the ray reflected from the glass surface. The fact that most of the light has to pass through the glass both to and from the reflecting surface makes the silvered mirror, from a

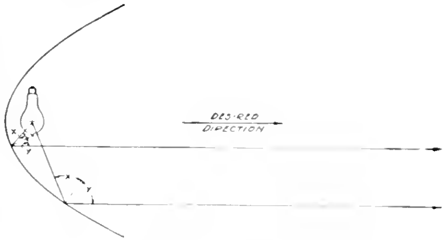


Fig. 2. Accurate Light Control may be Obtained from Polished-metal or Mirrored Surfaces

laboratory standpoint, a less efficient reflecting surface than the polished silver itself. For instance, if 100 lumens strike a mirror the reflections and absorptions are of the following order of magnitude: 10 are reflected by the exposed surface of the glass, 10 are lost by being absorbed by the silvered surface, and 5 are absorbed by the glass, leaving a total of about 75 lumens which are reflected by the silvered surface; the loss in the glass depends, of course, on the quality of the glass. The deterioration of a polished-metal reflecting surface in service is, however, a factor which often more than offsets its higher initial efficiency.

To obtain a desired distribution from a polished-metal or a mirrored surface, it is necessary that the contour of the reflector at each point be such that it makes equal angles with the incident ray at that point and the desired direction of light. For example, where parallel rays of light are desired, as in the case of automobile headlights, the cross-section of the reflector will have to be of the nature of that shown in Fig. 2, namely, a parabola. A hemispherical reflector, on the other hand, placed above the lamp with its center coinciding with the light source, will not concentrate the light at all but will nearly double the candle-power at each angle in the lower hemisphere, since each ray that strikes the reflector is reflected back along the same line, through the source and into the lower hemisphere. Mirrored reflectors have a disadvantage that they throw brilliant images of the filament, or striations, on the surfaces illuminated. In practice, these striations are often eliminated by corrugating the reflector or frosting the lamp, with, however, some loss in the control of the light.

Since polished-metal and mirrored surfaces follow definitely the law of regular reflection, these surfaces are used in reflectors where the aim is to obtain definite and accurate control of the direction of the light. The automobile headlight and the floodlighting units are the most familiar applications of polished-metal reflectors for accurate light control. Mirrored glass is also widely used for both direct and indirect lighting units.

Dull-finished or Semi-mat Reflectors

A dull-finished or semi-mat surface can be considered as one which has many small polished surfaces making innumerable slight angles with the apparent contour. A surface coated with aluminum paint affords a good example. When a shaft of light strikes such a surface, the individual rays are reflected at slightly different angles, but all in the same general direction, as shown in Fig. 3, A. This is known as spread reflection. The spread of the reflected beam indicated by the angle between lines *ac* and *ad* is dependent upon the degree of smoothness of the surface, the smoother the surface the narrower the angle. When the reflecting surface is viewed along the line *ba*, no distinct image of the light source is visible but only a bright spot of light.

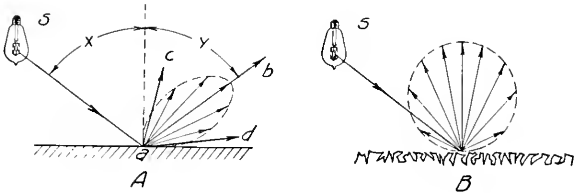


Fig. 3
A—Reflection from Semi-mat Surface
B—Reflection from Rough Mat Surface

The reflection characteristics of dull-finished or semi-mat surface reflectors are similar to those of reflectors having polished surfaces, with the exception that the light is redirected with less accuracy. The efficiency of dull-finished reflectors in the deep-bowl shape, for example, unless they are carefully designed, is likely to be reduced somewhat owing to cross-reflection from one side to the other and consequent absorption of the light—a condition which is not so likely to obtain in a polished reflector of the same shape. The aluminumized-steel reflector is the only commercial semi-mat reflector in general use. A form commonly employed is shown in Fig. 4.

Fig 4. Typical Aluminumized-steel Reflector

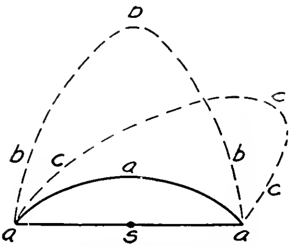


Fig. 5. The Shape of a Rough-surface Reflector has Relatively Little Effect on Distribution

Rough Mat-surface Reflectors

If a mat surface is so rough that it has absolutely no sheen, as, for example, the surface of blotting paper, and a beam of light strikes it, as indicated in Fig. 3, B, the light is likely to go down into one of the pockets and be reflected back and forth so that when it comes out the rays are sent in all directions. The result is that the whole surface appears equally as bright from one direction as from another, that is, just the same as it would if it were luminous from being heated to incandescence. In other words, the candle-power per square inch of apparent area is uniform. Under these conditions, the candle-power is a maximum in a direction perpendicular to the surface, for the surface has the greatest apparent area when viewed from this direction. When the measurement is made from any other direction the apparent area is less, and since the candle-power per square inch of apparent area is constant, the candle-power is less. White blotting paper is one of the best examples of the diffusing type of reflecting surface; a good sample will reflect about 80 per cent of the light which strikes it.

Since light which falls upon a rough surface is reflected in all directions, it follows that the shape of reflectors using such a surface has little effect on the resulting distribution of light. In Fig. 5, *S* represents a light source at the mouth of a rough-surfacer reflector *aaa*. The light distribution is the same when the reflector has the cross section *aaa*, *bbb*, or *ccc*, for when the reflector is viewed from below, it simply appears as a white disk. However, if a contour such as *bbb* or *ccc* is used rather than *aaa*, there will result a needless absorption of light due to cross reflection of light between the inside surfaces, and the light from *S* would, therefore, be utilized to better advantage with the shape *aaa*.

Reflectors having a rough reflecting surface are difficult to keep clean and are therefore seldom used, since opal glass and porcelain enamel offer the same advantages without this handicap.

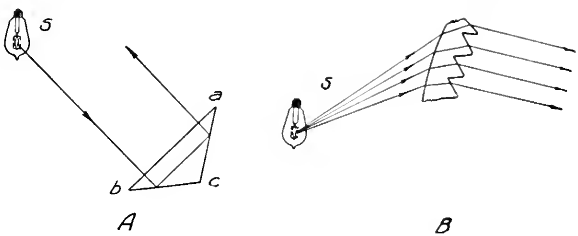


Fig. 6
A Reflection by Prism
B Refraction by Prisms

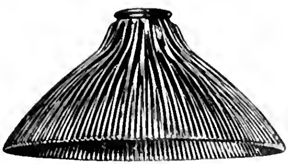


Fig. 7. Typical Prismatic-glass Reflector

Prismatic Glassware

Prismatic glassware, as it is usually employed in lighting units, is made up of many small prisms which compose the entire body of the reflector. The principle involved is that of total reflection, which is illustrated in sketch A of Fig. 6. The sketch shows the path of a single light ray; the angles of the prism can be made such that when the light ray passes into it and strikes the back surface *bc* it is reflected to the surface *a* and out again as shown. It will be observed that, for all practical purposes, this reflection is the same as would be obtained from a polished metal or mirrored surface, that is, each prism is the equivalent of a narrow strip of mirror. By tilting this strip longitudinally the direction of the reflected beam can be accurately controlled and by giving it the proper curvature the desired distribution of all the light falling on it can be obtained. The tips of the prisms are usually rounded slightly, which permits the transmission of a small percentage of the light and thus improves the appearance of the reflector. Prismatic glassware of proper design does not produce striations.

Dust on the exterior of a prismatic reflector reduces the light in the upper direction only, but moisture and moist dirt in optical contact with the exterior surface affect the reflecting power of the prisms and reduce the light output both upward and downward.

A typical prismatic-glass reflector is shown in Fig. 7. So-called velvet-finish prismatic-glass reflectors are also available. These reflectors give a distribution similar to that of a semi-mat or dull-finished reflector, for, as will be discussed in a subsequent paragraph, the etching on the inside surface of the reflector gives spread characteristics to the reflected light.

and light. The properties of opal glass can be most readily understood if we regard it as common glass, in which fine white particles are, so to speak, held in suspension. When a ray of light strikes this surface, part of the light is reflected directly, as in the case of a polished-metal surface. The remainder of the light travels through the glass in straight lines until it strikes the white particles, or any minute air bubbles which may be present, whence it is dispersed in all directions, some of it being thrown back and reflected as shown in Fig. 8, A, and the remainder being transmitted through and out in all directions. If, by chance, any of the light passes through the glass and fails to strike any of the white particles, it goes out in a line parallel to the one along which it entered. Thus, if a lamp

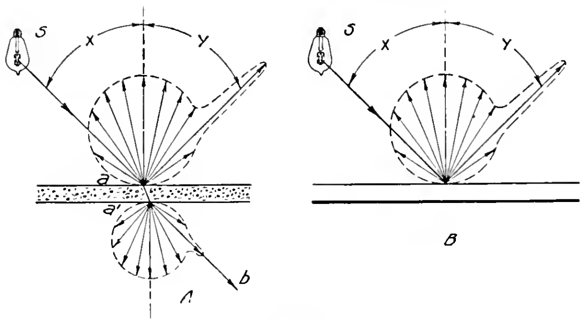


Fig. 8
A—Reflection and Transmission by Opal Glass
B—Reflection from Porcelain-enameled Steel

Prismatic glassware is also used for refracting or changing the direction of light rays passing through. The prisms used in refractors are of different shape from those used in reflectors. The paths of light rays through four prisms of a refractor are indicated in Fig. 6, B. Refractors are commonly used where a very broad distribution of light is desirable as in the case of street lighting.

Since with both prismatic reflectors and refractors the light is reflected by or passed through clear glass only, the absorption is low and the efficiency of such glassware is of the highest order.

Opal-glass Reflectors

Opal glass finds considerable application in illumination practice both as a reflecting and a transmitting medium. In general, there are two types of opal glass, classed as dense

were enclosed in a ball of opal glass, through which on the average, say, one ray in a hundred could pass without striking any of the white particles, the filament outline would be visible if viewed from the proper direction; in the case of Sketch A of Fig. 8, this would be in the direction *ba'*.

The effectiveness of opal glass in redirecting light depends upon the number of white particles and their density in the glass. An opal glass which permits only about 10 per cent of the light striking it to pass through is classed as very dense; light opals may allow as much as 60 per cent to be transmitted. A totally enclosing opal-glass ball may, however, have an over-all output as high as 80 per cent, for while only 60 per cent of the light coming directly from the lamp to a point on the surface may be transmitted, sufficient light may come to this point from the illuminated interior of the ball to bring the total transmission of the ball up to 80 per cent. For a typical test piece of glass of the common commercial type, with 40 per cent transmission, about 10 per cent of the total is directly reflected, 10 per cent is absorbed by the glass and the other 40 per cent is reflected in all directions.

Dense opal glass need not necessarily be thick. A thin coating of a dense mixture may be "flashed" on a body work of clear glass of ordinary thickness and thus produce what is known as flashed opal. Tests have shown that such glass absorbs less light than ordinary opal glass of equal diffusing power and hence flashed opal is particularly adapted to use in enclosing units, where the lightest density which will hide the filament is desirable and where greater density will result in unnecessary absorption.

Two important advantages make opal glass a very desirable reflector material. These are: (1) its smooth surface minimizes the collection of dust and permits easy cleaning; and (2) the glass transmits a portion of the light, which renders the reflector luminous and thereby adds materially to its appearance. These two advantages are largely responsible for the wide use of opal glass for reflectors and reflecting equipment.

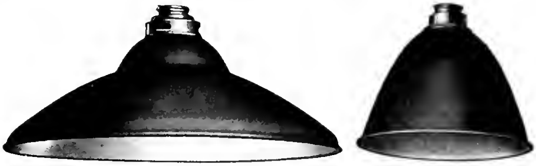


Fig. 9. Dome and Bowl Shaped Porcelain-enameled Steel Reflectors

Fig. 10. Metal-cap Diffusing Unit

Opal glass is used for open reflectors, semi-enclosing units, for balls, stalactites, and other forms of enclosing diffusers, and for semi-indirect units. Due to the fact that the reflected light is diffused, the contour of the reflector is a less important factor than in the design of mirrored glass or prismatic reflectors, and is determined largely by the appearance desired. Lighting units using opal enclosing glassware are popular for use with Mazda C lamps because of the good diffusion obtained for a direct-lighting fixture and because of the variety of attractive designs which are available.

In the case of semi-indirect lighting, it should be remembered that one of the main advantages of this system is the possibility of reducing the brightness of the light source so that it is comparable with its surroundings, and care should, therefore, be taken in the selection of such units for offices, school rooms, and the like, to select a sufficiently dense glass.

Porcelain-enameled Reflectors

In the familiar enameled-metal reflector, the surface, so far as its optical characteristics are concerned, can be considered as a plate of opal glass in optical contact with a steel backing. This opal must be very dense so that as little light as possible will pass through, for all the light that penetrates to the steel backing is absorbed, and therefore wasted. Enamels vary considerably in efficiency and if of two reflectors one appears gray in comparison with the other, it is sure to be considerably lower in efficiency. Sketch B, Fig. 8, shows the characteristic distribution of a porcelain-enameled surface on steel.

Porcelain-enameled reflectors find their principal use in industrial plants, where the advantages of efficiency, ruggedness, and permanency of reflecting surface are important.

Porcelain-enameled reflectors are commonly classified by shape as dome or bowl. These shapes are illustrated in Fig. 9. In general, the dome reflectors are more desirable when used with bowl-frosted Mazda C lamps because of their higher efficiency and the larger apparent size of the light source. Other things being equal, the larger the

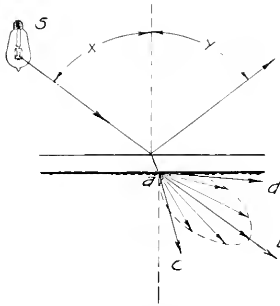


Fig. 11. Reflection and Transmission by Etched Glass

diameter of the source, the less the glare, the softer the shadows, and the less the annoyance from glaring reflections. In selecting any dome reflector, care should be exercised to see that its lower edge extends appreciably below the lamp filament.

A reflector which, while it employs porcelain enamel for its principal reflecting surface, also makes use of a polished-metal cap which is placed over the tip end of the lamp to redirect all the downward light upward against the porcelain-enameled surface whence it is thoroughly diffused and directed downward, is shown in Fig. 10. The light from this unit is characterized by freedom from glare, and the shadows are soft with gradually fading outlines. This unit finds its principal use in industrial plants where Mazda C lamps of 150 watts or larger are used and where reflections in polished surfaces would prove annoying if ordinary reflectors were employed.

Frosted-glass Reflectors and Globes

Frosted glass transmission characteristics may be likened to the reflection characteristics of a semi-mat surface. Fig. 11 shows the direction of a beam of light striking glass, the upper surface of which is smooth and the lower surface sand-blasted or roughed with acid etching. Some of the light is, of course, reflected from the glass as is shown in the figure, but most of it goes through the glass, and as the individual rays strike the rough surface they are partially dispersed. When the surface is viewed along the line *ba*, the light source is visible only as a bright spot. A familiar illustration is a frosted Mazda C lamp, in which only a bright spot, showing the presence of the filament, but no distinct outlines, is visible.

Etched glass should be used to give a spread transmission of light rather than as a good reflector. It is of little value except for enclosing units. Unless a frosted glass surface is of a very fine texture, it accumulates dirt rapidly and is difficult to clean. A recent tendency in illuminating engineering has been to make use of stippled or pebbled glass which has the diffusing characteristics of sand-blasted glass without the same difficulty of cleaning. Glasses of this character are especially valuable where it is desired to transmit light without greatly changing its direction.

Secretary of the Navy Daniels Visits Schenectady Plant

On Saturday, June 15th, the Schenectady Works of the General Electric Company [illegible] visit from Secretary of the Navy Josephus Daniels. Following a hurried morning tour of [illegible] the 350-acre plant, he laughingly remarked, "After we have won the war I shall come back to Schenectady for a month or two so as to have time to go through this plant." At noon, he was introduced to an [illegible] out-door audience of 20,000 men and women employees, by G. E. Emmons, a vice president of the Company. The substance of Secretary Daniels' address is quoted below.—EDITOR

"Ladies and fellow countrymen, there is a regulation in the United States navy that a naval officer must walk ten miles each month in a very short time. This morning I believe I have complied with the regulations, but I have seen only a very small portion of this vast establishment.

"There is a feeling in some parts of the country that the navy is afloat, that the navy must be on the blue. Today we know that the navy is in these shops as well as on the high seas. The navy of today was never before as safely anchored in the confidence and affections of the American people. When our country, after using all the statesmanship and diplomacy that our great President could employ, found that America had to take part in this world war, we had the navy in English waters in a few days. Almost immediately we entered upon a program of construction never before dreamed possible.

"There is a motto in our navy that reads, 'The thing is impossible, now let's do it.' When we decided that the most effective weapon against the Hun murderer of non-combatants on the high seas was the destroyer, we began to build more destroyers than all the other nations of the world had put together. We called upon you and when I say *you*, I do not mean the president of this company any more than I mean the skilled worker—to help.

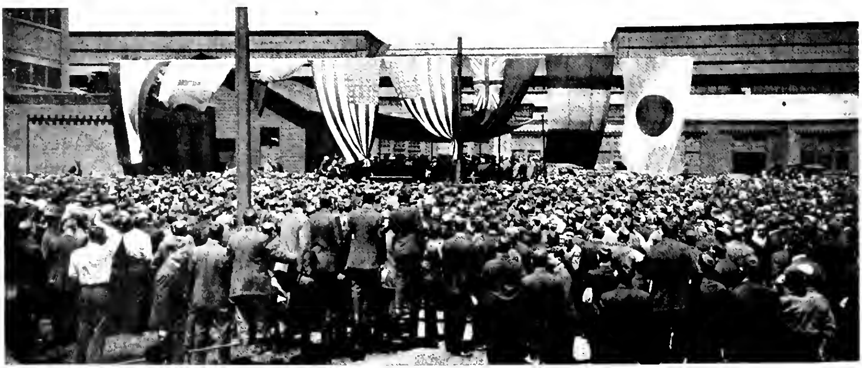
Let me say here that it is the wisdom of the selective draft to utilize every man where he can best serve his country. In the early days of the war France and Great Britain called their skilled laborers into the field. But they had to be recalled very soon, as their places could not be filled. In this country we have sought to avoid this mistake. And I want to say to you men, you skilled laborers, you turbine builders, you constructors of gears and electrical apparatus, your place is here. Gentlemen, every day that you turn out more and better equipment for our army and navy, you are as truly fighting as are those brave men in the mud and glory of France.

"Before the war our scientists and skilled men were busy in the arts of peace, to till the farms, to make machinery, to build ships—all to make life better and insure happiness for all. Unless a man's brains are employed to make all the world better, he is not employed for a true American purpose. We never believed that the men who labor and think, the scientists and inventors of Germany could be so driven into rapine and murder by that international outlaw of the world who has plunged us into blood. Their scientists and skilled men thought of every invention, of every new discovery, as to how it could be saved and applied for 'der tag' the day when they would seek to ride on the backs of the world and make all men do their will.

"When the war came we turned to the men of skill and invention, to such men as I see before me here in Schenectady today and we are demonstrating that American genius and American skill are the equal of any in the world.

"There is nothing in America today that belongs to any individual. This plant belongs to Uncle Sam. I belong to Uncle Sam, you belong to Uncle Sam, and I know that you haven't an ounce of power or a dollar's worth of property but what will be consecrated, if necessary, to winning this war. There is only one business in America and that business is winning the war. If there is any man who thinks of business as usual at this critical time, he is not American. If there is any man in the field [illegible] factory working [illegible] thinks [illegible] he has not the right spirit of liberty.

"It is a great [illegible] to find that Americans on the Pacific coast, on the Atlantic coast, on the Gulf and on the Canadian border are of one heart and purpose. We [illegible]



Secretary of the Navy Daniels arriving at the Schenectady Plant, awaiting to be introduced to the assembly of workers, and delivering his address beneath flags of the Allied Nations

Revolution, or to the '60's, to find inspiration for prosecuting this war, for we can find it in the millions out of our own homes—homes as patriotic as any in the world.

"We used to hear of common sailors, but there are no common sailors now. There are 500,000 uncommon sailor heroes. You are building here the motive power for destroyers and cruisers which will soon sail the ocean. And these ships in which you have put your labor and your skill in the last few months have carried 700,000 soldiers to France without the loss of a man. And when we have finished, these boats will convoy not 700,000 but 7,000,000 if necessary.

"There is no rank in sacrifice in America today. The best American is the man who is doing the most to win the war in any way he can serve best. All of us, whether the great President in the White House—the greatest spokesman of liberty in the world—or General Pershing on the field of France, or Admiral Sims leading our fighting navy abroad—you men in the research department, you women in the offices and factories, you boys here before me, are putting the character in the work that is going to win the war. It is a happiness, it is a matter of profound congratulation that all over America men and women are hearing the call of duty and answering it. We live in the greatest golden age of all the world, an age when men and women are giving their lives, their hearts, their all to preserve the liberties our fathers bought with their blood. And we are going to win this war. I am as sure of our winning as that God rules in the heavens. I wish you to know that every hour I labor and try to serve, every hour that you work here in the shop, all of us are servants of the great constituency. There is no man in America who can call himself king, emperor, or kaiser. We are but one people, with but one purpose, and that is to win the war.

"I shall go to Washington with the story of your work here in this city of Aladdin. But you in Schenectady could teach Aladdin a lesson he never dreamed of. I shall gladly talk of the team work among you fellows and associates, and the team work of the entire country, for there is no work in the world except team work. All of us have a place by doing our part, whether the great commander of America's forces, the man who stands on the deck of a destroyer without sleep or food, or the man in the shops who is making ships.

"If we put our character, our religion, and our patriotism in our work, when the war is over and liberty is preserved for the world, there is not a man or women here, as the years go by, who will not be proud to say that he had some part in the work of saving the world for democracy and civilization.

"I thank you for your hospitality, and I shall go back to Washington heartened and cheered by what I have seen. And when I tell our great President that I have seen the men in the factories, on the farms, and in the offices who are holding up his hands, who are ready to give their lives, to give all for victory, it will cheer him and guarantee success to our arms."

* * *

The stand from which the secretary spoke was decorated with the flags of the nations now fighting side by side with the Allies. Seated on the platform were Governor Charles S. Whitman, former Governor Martin H. Glynn, Lieutenant Governor Edward Schoeneck of Syracuse, Commander Carter, Speaker Thaddeus C. Sweet of the state assembly, State Senator James W. Yelverton, Assemblymen Walter S. McNab and A. Edgar Davies, Charles A. Simon, Mayor of Schenectady; Edwin W. Rice, Jr., G. E. Emmons and J. R. Lovejoy, Commodore J. T. Newton, U. S. N.; Major F. L. B. Hoppin, Colonel C. E. Pruyn, who had charge of the program; Captain P. E. Barbour of the state police, Colonel William P. Dauchy, Brigadier General F. DeF. Kemp, Lieutenant T. A. W. Shook, and Ensign A. S. Rollins.

Self-restoring Properties of Lightning Arresters

By H. G. Brinton

Pittsfield Works, General Electric Company

When a dangerous voltage disturbance occurs on a transmission line the dielectric of the lightning arrester gap breaks down and the arrester discharges to ground. The path from line to ground is then completely conducting and it is apparent that some means must be provided for interrupting the dynamic or power current and restoring the arrester to its normal condition. Practically all modern arresters are self-restoring and accomplish this function without being disconnected from the line. In this article are described the self-restoring properties of the more common types of lightning arresters that are in use today.—Editor.

A lightning arrester is defined by the A.I.E.E. Standardization Rules as "a device for protecting circuits and apparatus against lightning or other abnormal potential rises of short duration." The advantages and importance of this protection in the interests of real economy and of continuity of service have been increasingly appreciated, until today good engineering practice requires the use of lightning arresters with nearly all installations. The definition given above of a lightning arrester would include condensers which have had some application as a protection against certain classes of disturbances. The use of condensers as lightning arresters will not, however, be considered in the present article.

The most important electrical features of a lightning arrester are:

(1) The spark potential characteristics.

(2) The discharge rate, which depends upon the impedance of the arrester circuit.

(3) The self-restoring properties.

(4) The general arrangement of the arrester and connections with respect to the apparatus to be protected.

In addition to the above, there are a number of properties which are desirable or necessary in lightning arresters, as in other electrical apparatus, and for the same reasons.

Any of the usual types of lightning arresters with their connections can be regarded, from one point of view, as a path from line to ground (or line to line) which includes one or more gaps of comparatively weak dielectric. The gap dielectric should be relatively weak compared with the insulation strength of the apparatus to be protected, but, of course, must be strong enough to withstand the normal line voltage. The voltage required to break down the gap dielectric is called the spark potential of the lightning arrester. The lightning arrester gives protection because the weakest point will be the one to break down. However, in order to obtain the most favorable conditions in this respect the lightning arrester must be connected near the apparatus to be protected. Lightning arresters are necessary not only to protect the apparatus against excess voltage disturbances which would have to occur but once to puncture unprotected insulation, but to protect against voltage disturbances of somewhat less severity which by repeated occurrence would produce a progressive weakening and ultimately a break-down of unprotected insulation.

When an excess voltage disturbance occurs on the line, the dielectric of the lightning arrester gaps breaks down, or, as it is usually stated, the arrester sparks over. The arrester path from line to ground then becomes completely conducting and the line is relieved of the excess voltage disturbance by a discharge to ground through this conducting path.

It is apparent that some means must then be provided for restoring the arrester to its normal condition and interrupting the dynamic or power current which would otherwise continue to flow through the arrester path to ground. Arresters provided with such a means have been called self-restoring or automatic lightning arresters. Self-restoring lightning arresters should be used for line to ground connection even on non-grounded circuits, as one line may become temporarily grounded or two arresters may spark over at the same time.

An arrester may be provided with a means for current interruption and yet not regain its normal condition after a discharge, as in the case of an arrester depending upon a series fuse. Practically all modern arresters are self-restoring, and fuses are sometimes installed only as a precaution against the failure of the self-restoring means. A fuse is then used of such capacity that it will blow only in case the arrester is unable to clear itself.

The self-restoring property of a lightning arrester should operate without increasing the spark potential of the arrester or disconnecting the arrester, even momentarily. The arrester must be ready at every instant to perform its function of interposing a dielectric between line and ground which is weak compared with the strength of the insulation to be protected. For safe operation of the self-restoring means and to avoid momentary short circuits, it is necessary in most arresters to use series resistance, but the resistance and inductance of the arrester circuit should be kept down to a reasonable value which is determined largely by experience.

The present article deals specially with the self-restoring properties of the various types of lightning arresters manufactured by the General Electric Company. It is assumed that the reader is somewhat familiar with the general designs of these arresters, which have been described in numerous articles. Although the means which make these arresters self-restoring differ widely, each depends, in part at least, upon the characteristics of electric arcs. The characteristic which especially distinguishes an arc from other conductors is the increase of voltage across the arc with decrease of current. With a large current the voltage drop across an arc is low, but with comparatively small currents the voltage drop is high. As the current is decreased in a given circuit, the voltage drop can shift from the rest of the circuit to the arc, but the voltage drop across the arc is limited to less than the circuit voltage. By decreasing the current it is therefore possible to obtain conditions under which an arc cannot exist, as the voltage corresponding to the small values of current is not available. The exact voltage drop for a given current varies greatly, depending upon the general conditions under which the arc exists. Any arc can be broken, however, by decreasing the arc current sufficiently.

The Magnetic Blow-out Lightning Arrester

The gap of this arrester is an air gap between two metal electrodes. The gap is in the field of an electromagnet which is excited by a coil connected across part of a resistance in series with the gap. An insulating arc chute protects the electromagnet from the arc which forms between the gap electrodes at times of discharge through the arrester. A single gap is used for 600 and 1200-volt, direct-current circuits, and several gaps in series for higher voltages. The arcs at the gaps are broken as a result of increasing the length and thereby the resistance of the arcs. The arc current is thus decreased and the arc broken without increasing the spark potential or the resistance in the discharge path of the lightning arrester. The movement of the arc is in accordance with the rule that a current-carrying conductor placed in a magnetic field tends to move away from that side on which its own field or a component of its field is in the same direction as the given field. As the arc is lengthened out and the current decreases, the strength of the magnetic field also decreases; but this does not correspondingly affect the further movement of the arc, as the arc vapors are thrown away from the electrodes with considerable velocity. It is possible to use this type of arrester on alternating-current circuits, since the magnetic field reverses with the current and consequently the forces exerted on the arc are not affected by the direction of the current. It is used, however, only on direct-current circuits, as there are other types which are more suitable for alternating-current circuits.

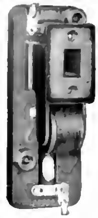


Fig. 1. Magnetic Blowout Arrester for Indoor Service Up to 750 Volts

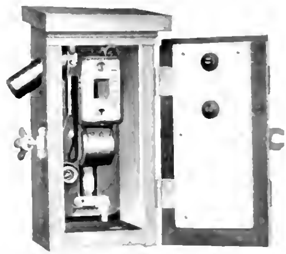


Fig. 2 Magnetic Blowout Arrester for Outdoor Service Up to 750 Volts

The Horn Gap Lightning Arrester

The gap of this arrester is an air gap between two metal horns. The arc which is started by a discharge through the arrester is broken as a result of the decrease of current as the arc rises on the horns and increases in length and resistance. The movement of the arc is partly due to the fact that each part of the arc is a current-carrying conductor in the field produced by the current in the horns and in the other parts of the arc. This produces a magnetic blow-out action. The heating of the surrounding air produces an upward draft which also causes the arc to rise. In the case of an exposed horn gap the arc may be blown out by the wind more rapidly than it

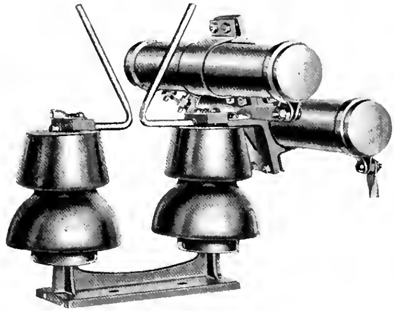


Fig 3. Horn Gap Arrester for Outdoor Service

would be lengthened out by the other actions. A longer time is required to break the arc with this arrester than with the other types of arresters; consequently, there is considerably more heating of the series resistance. Several seconds may be required to break the arc in

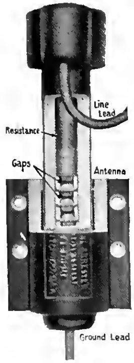


Fig. 4. Multigap Arrester

some cases. It is practically necessary to use series resistance with horn gap arresters in order to avoid momentary short circuits and to prevent the production of severe voltage disturbances when the arc is broken. No reasonably cheap resistance has yet been produced which is satisfactory for general use with horn gap arresters on all circuits. The application of this type of arrester has, therefore, been limited to the protection of constant current lighting circuits where the current is limited to a small value by the

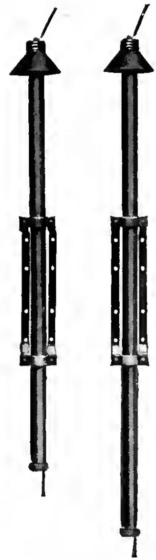


Fig. 5. These Arresters Consist of a Combination of Gaps and Resistance Rods Mounted in a Porcelain Tube

characteristics of the constant current transformers.

The Multigap Lightning Arrester

The gaps of this arrester are air gaps between metal electrodes. The number of gaps used in series is increased with the voltage of the circuit in order to keep the voltage per gap at a fairly low value. This type of arrester is satisfactory for and is used on alternating-current circuits only. The dynamic current which follows a discharge across the gaps is, therefore, automatically reduced to zero within one half cycle or less. As the current decreases the arc resistance increases. The increase in resistance is due largely to the cooling of the metal electrodes and the metallic vapors which carry the current. If the resistance has become great enough and the rate of increase of the voltage wave is not too rapid, the current will not start again after passing through the zero point. To obtain these favorable conditions, the dynamic current is limited by series resistance or other means and the voltage per arc is limited by the use of a number of gaps in series.

With certain gap combinations, the resistance of the arcs becomes much greater than with others as the current decreases, and such gaps are usually called "non-arcing," as other combinations are non-arcing only at a much lower circuit voltage per gap. The arc vapor in the case of the usual non-arcing gaps is zinc from the alloy electrodes. An action between the zinc vapor and the oxygen of the air is the cause of the special non-arcing property, as was originally suggested by Wurts. That this is true is shown by the facts that zinc is one of the best metals for maintaining an arc in hydrogen, and that with other metals than the so-called non-arcing metals it is easier to maintain an arc in air than in hydrogen.

The Direct-current Aluminum Cell Arrester

In the direct-current aluminum cell arrester the films on the aluminum anodes or positive plates form the gaps in the otherwise conducting path through the cells. The films are thought to consist of very thin porous layers of aluminum oxide, with the pores more or less filled with oxygen. The film is formed on the positive plate or anode by the passage of current through the cell. The oxide coating is practically non-conducting and any current, except capacity current, passes by means of a discharge through the oxygen between the electrolyte and the aluminum plate. The thinness of the film precludes any detailed observations or study of the discharge itself. It is known, however, that the discharge is not maintained at a voltage much less than that required to start it, and for this reason the action of the cell has been described as a valve action. This characteristic of the discharge through the film may be partly due to one electrode being an electrolyte instead of a metal. It requires a much higher voltage to maintain a discharge across a gap when one electrode is an electrolyte than when both electrodes are metals. On account of its extreme thinness the aluminum film has a very large capacitance. This capacitance is in multiple with the discharge through the film and may aid somewhat in the stopping of the flow of current through the film, or what has been called the sealing action of the film. A capacitance in multiple with an arc tends to increase the instability of the arc. The film capacitance also increases the protective ability of the arrester.

A single film cannot be formed up to withstand more than a few hundred volts without a discharge, and consequently a

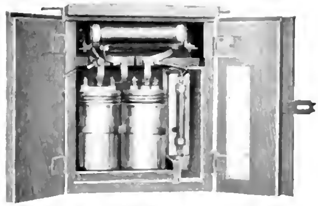


Fig 6 Aluminum Cell Arrester for Car or Indoor Use

number of cells are ordinarily used in series. The discharge voltage with the electrolyte positive is very low, although it may be 300 to 400 volts with the aluminum plate positive. This property enables the aluminum cell to be used as a rectifier but is of no particular importance to lightning arresters except in the case of certain direct-current arresters on which the voltage may be reversed. In this case it is necessary to keep the films built up on both electrodes of each cell by charging in both directions, that is, by connecting the cells to the line first in one direction and then in the other. A series air gap should be used in this case, as the films would dissolve off the negative plates much faster if the cells were connected to the line continuously. Where there is no danger of the voltage reversing, the cells are used without a series gap. In the direct-current aluminum cell arrester the film will withstand the normal voltage per cell of the circuit, but any excess voltage disturbance will cause a discharge through the cells. The discharge stops when the voltage drops to normal. Slight increases of line voltage are not harmful to the arrester, as the films form up very quickly to the higher value.

The Alternating-current Aluminum Cell Arrester

The cells of this arrester are electrically similar to those of the direct-current aluminum cell arrester. They are ordinarily used, however, with a series air gap. The films are kept formed by short-circuiting the series air gap for a few seconds each day. The films are formed on a given aluminum plate only when that plate is positive. The film starts to dissolve when the plate becomes negative. The dissolution is very slow, however, compared with the formation, and consequently the cells can be formed on alternating current. The cells are not ordinarily connected directly to the line because the losses in the cells heat the electrolyte, which greatly increases the film dissolution. The condition of the cells may become dangerous if an ordinary alternating-current arrester is left directly connected to the line for several

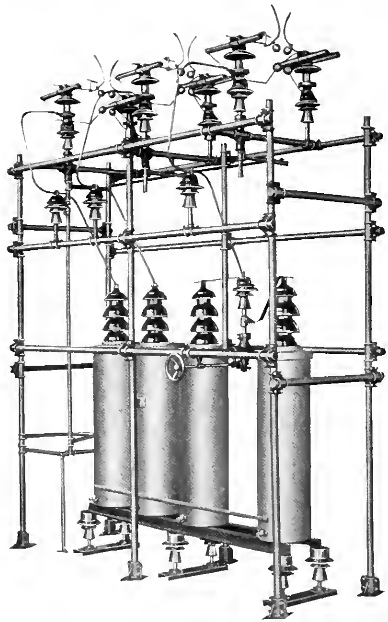


Fig. 7. 35,000-volt Three-phase Aluminum Cell Arrester for Outdoor Installation

hours. The self-restoring action of the alternating-current arrester is similar to that of the direct-current arrester as far as the power current is concerned. The alternating-current cells, however, take a capacity current of 0.3 to 0.1 of an ampere at 60 cycles. This capacity current is interrupted by the action of the series air gap. The dissolution of the films of alternating-current cells is slow, and ordinarily the arrester can be kept in good condition by charging, or connecting the cells to line for 5 to 10 seconds each day.

The Vacuum Tube Lightning Arrester

This arrester is used for the protection of very low voltage circuits. The gap is in a vacuum tight container which is filled with a gas at a pressure much below atmospheric pressure. The object of the partial vacuum is to obtain a spark potential of a few hundred volts without reducing the gap spacing to a value which would be impractical for a lightning arrester. With a given gap spacing the spark potential decreases as the gas pressure is decreased, until a certain minimum value of spark potential is reached, after which the spark potential increases as the pressure is further decreased. The spark potential of the General Electric vacuum tube arrester is 300 to 600 volts direct current. The spark potential of the same gap in air at atmospheric pressure would be about 4000 volts direct current. Somewhat less voltage is required to maintain an arc across the gap at the reduced pressure than at atmospheric pressure. The arrester is used only on telephone circuits and some signal circuits, and the line voltage of these circuits is too low to maintain an arc across the gap.

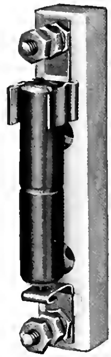


Fig. 8. Vacuum Tube Lightning Arrester

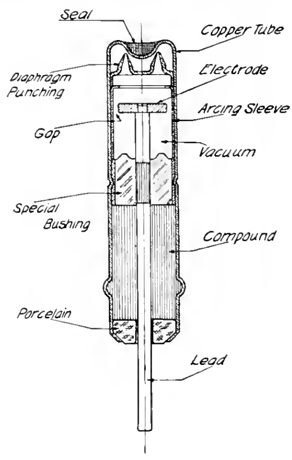


Fig. 9. Construction of Vacuum Tube Lightning Arrester

Protection from Flashing for Direct-current Apparatus

By J. J. Linebaugh and J. L. Burnham

Railway and Traction Dept. and Direct-current Engineering Dept., General Electric Company

The equipment developed for the protection of direct-current apparatus as described in this article is applicable to all direct-current apparatus and all methods of operation. Special means of protection for use only with particular apparatus or conditions of operation have not been mentioned. The principal steps in the experimental development of high-speed circuit breakers and flash barriers are briefly given. The protection afforded by the high-speed breaker or barriers is sufficient for most apparatus and service, but *complete* protection for *any* direct-current apparatus and service requires both the high-speed breaker and flash barriers. Attention is directed to the importance of arranging the connections to the brush rigging so that the magnetic action on the arc will be a minimum and properly directed, so the flash will do the least damage. This article was presented as a paper at the Thirty fourth Annual Convention of the A.I.E.E., Atlantic City, N. J., June 28, 1918.—Editor.

The problem of protection from flashing has for many years confronted engineers who build and operate direct-current machines. Numerous schemes and suggestions have been put forward which it was hoped would overcome the tendency to flashover on extra heavy overloads or short circuits. Some time ago it was felt that the subject of prevention and protection from flashing had not received the study and investigation justified by the trouble experienced, and it was decided to make a comprehensive study of the entire subject.

Some form of barrier has been the most common protection suggested, and different forms have been tried with a slight degree of success on some machines and absolute failure on others. It was the opinion of many engineers that barriers could not be designed to take care of a short circuit and that their value was doubtful. However, a special form of barrier, which gives the required protection, will be described later.

It was realized that the means for prevention of flashing at the commutator and brushes of direct-current machines must operate to remove the cause very quickly. The use of some form of high-speed device, which would open the circuit or insert resistance before the short-circuit current could reach a value which would cause flashing, seemed the most logical way to solve the problem, although it was appreciated that the action of the device must be much more rapid than any commercial circuit-opening device previously produced. An investigation was conducted along these lines and two distinct types of high-speed breakers developed, which will be described separately.

A flash at the commutator starts from excessive sparking. Sparking is produced by the breaking of current in the coils short-circuited by the brush as each segment of the commutator passes from under the brush. As the coil is inductive, the spark or arc tends to hold and, if the arc is of sufficient volume,

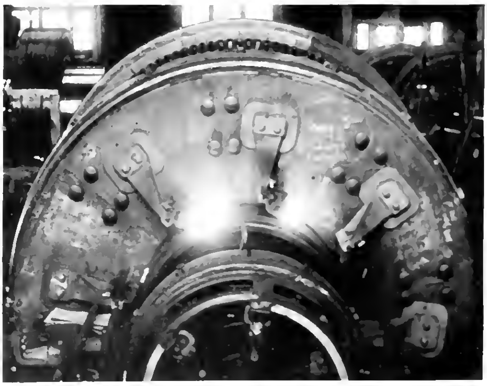


Fig. 1. Flashing at Brushes on 1000 kw., 1500 volt Generator Forming Part of 2000 kw., 3000 volt Motor generator Set at Five Times Load. Showing Different Stages of Arc Formation

the vapor produced thereby forms a low resistance path between segments and from brush to brush or to frame, through which a large current may pass. See Figs. 1 and 2.

Sparking may be prevented by providing a magnetic field of proper strength and distributed to influence the coils during reversal of their current as they pass through short circuit by the brushes. To provide the correct commutating field for all conditions

Fig. 2. High-speed Photograph of Flashing on 300-kw., 600-volt, 25-cycle Synchronous Converter with Short Circuit on 0.015 Ohms Additional in the External Circuit and Standard Circuit Breaker

Fig. 3 High speed Photograph of Short Circuit on 300-kw., 600-volt, 25-cycle Synchronous Converter with Standard Circuit Breaker

of load has been the object of designers but success has been only partial. At high loads, saturation of magnetic circuits and distorting influence prevent attainment of the desired field, and for sudden changes in load the changes in field cannot be properly synchronized. It is more difficult to avoid sparking with rapidly varying loads than with gradually changing or steady load, but if a sudden load which would cause flashing is of short enough duration, the arcing at brushes may not produce enough conducting vapor to establish an arc supported by the main voltage. *The value of load that causes flashing when applied suddenly (short circuit) is a function of the time required to throw it off.* The quicker the circuit is opened the higher the value of current that will not cause arcing.

With the ordinary circuit breaker which begins to open in about 0.15 second, there is a certain maximum load which cannot be exceeded for each commutating machine without causing flashing. If feeders have sufficient resistance to limit the short-circuit current to this critical value, flashing will occur only on the rare occasion of a short circuit in a feeder itself. See Fig. 3. It has been the standard practice of nearly all manufacturers to recommend tapping the feeders, especially railway feeders, at a sufficient distance from the substation to insure enough resistance in the circuit to limit current in case of short circuit near the station.

Inductance may be added to the circuit to retard the rate of increase of current on short circuit to such an extent that the ordinary breaker will have time to trip before the current in the machine reaches a value that would cause flashing. The amount of inductance required to delay the rise in current sufficiently, however, introduces other disadvantages which make its use undesirable. When the current is interrupted, the increase in voltage from inductive "kick" is difficult for circuit breakers to handle and introduces the possibility of applying dangerous voltage stresses to the apparatus.

Reactors have been tried in a few instances with some success, but it has always been a mooted question whether the resistance of the reactor did not give as much or more protection than the inductance of the coil, and if this is the case resistance only would be much cheaper to install. A coil to give the delay required is usually very large and expensive and occupies much valuable space, giving a total cost out of proportion to the cost of the machines protected or the protection obtained.

With special high-speed circuit-opening devices operating in about 0.005 second, the more sensitive machines, such as 60-cycle synchronous converters for railway voltages may be short-circuited without flashing over, even though the maximum current is of higher value than would cause flashing with suddenly applied load and ordinary circuit-breaker protection.

The speed at which a circuit breaker must operate to prevent flashing depends on the amount of load thrown on the machine but, under worst conditions, our tests seem to confirm that it must be *quicker* than one half cycle of the machine to be protected. The time of operation of the breaker would be measured between the time that the current reaches the flashing value to the time that the current is again reduced to the same value after the breaker opens. If the arc formed between two segments is not blown out as they pass from one set of brushes to the next, and all following segments have similar arcs formed between them, the arc would completely bridge between positive and negative brushes in one-half cycle, which would complete the flashover. Complete flashover might also occur from gases being blown by windage, magnetically, or by expansion, to increase or decrease the half cycle time.

The time of operation of circuit breakers as given herein is measured from the beginning of short circuit to the instant the breaker begins to reduce the current rise.

Investigation covering these several schemes of protection was made, which it is believed will be of interest and will be described briefly with oscillograms, reproductions from photographs, etc., showing behavior under different loads and short-circuit conditions.

All short-circuit tests were made by connecting positive and negative terminals with a 500,000 circular mil cable, the only equipment in the circuit being the necessary current shunt for the oscillograph, a contactor to close the circuit, and a circuit breaker for overload protection, in addition to the protective device being investigated. Power for the 300-kilowatt 25-cycle, and 500-kilowatt, 60-cycle, 600-volt synchronous converters, used in fuse, barrier, reactor, and high-speed circuit breaker tests, was supplied from a 6000-kilowatt frequency changer set only a few feet from the test, so that there was very little drop in the voltage of the

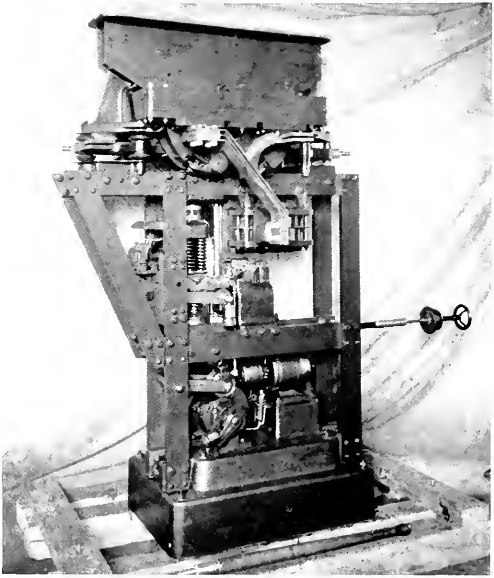


Fig. 4 3000-ampere, 3600-volt, Direct-current, High-speed Circuit Breaker

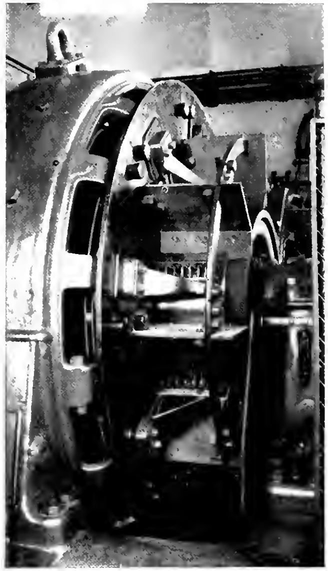


Fig. 5. Type of Flash Barrier Installed on 2000-kw., 3000-volt Synchronous Motor-generator Set Used in Connection with High-speed Circuit Breaker

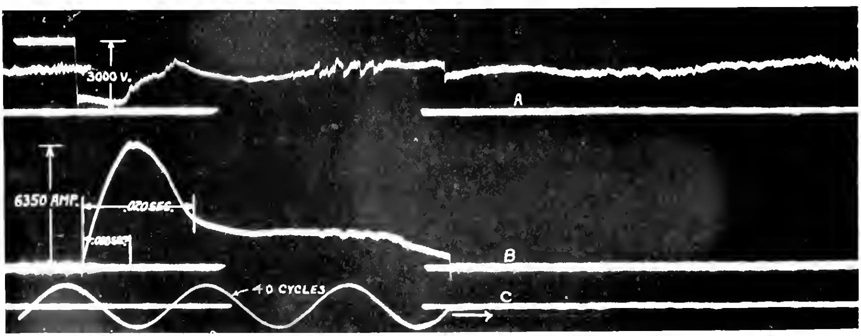


Fig. 6 Direct-current Short Circuit on 2000-kw., 3000-volt, Motor-generator Set with High-speed Circuit Breaker and Standard 3000-volt Switchboard Type Circuit Breaker

generator or from resistance, and the oil switch was set so that it did not trip out.

High-speed Circuit Breaker

At the time this development was started it was felt that if a circuit breaker could be designed to operate *within* the time required for a commutator bar to pass from one brush to another; that is, within one half cycle, protection would be afforded against practically any short circuit. Designs were therefore begun on a circuit breaker which would open within 0.007 second, which would cover most commercial machines, i.e., for 60 cycles and lower fequency.

High-speed breakers had been suggested and attempts made to produce such devices previous to this time but, as far as the writers know, had never been made to obtain as high speed as the discussion shows would be necessary.

Different types of construction were studied and samples of several preliminary models constructed without obtaining the speed desired. One of the most promising types of construction considered consisted of a knurled flywheel operating continuously with a knurled cam, so designed and located that a current relay would insert a wedge between the wheel and the cam and trip a breaker attached to the cam by suitable toggle mechanism. This preliminary sample indicated that 0.035 second was the best speed that could be attained.

It was then decided to concentrate all energies on a circuit breaker using the well-known principle of a latch, heavy spring and series tripping coil, and the high-speed breaker shown in Fig. 4 was finally built.

The problem was to obtain very quick tripping, rapid acceleration of contacts and a sufficient number of ampere turns in the magnetic blowout to insure rapid breaking of the arc. Previous ideas of design had to be abandoned when working for such high speed, when a loss of 0.001 second meant a very serious increase in time of operation.

It was found that a series blowout coil had to be used, as sufficient time could not be allowed for the building up of a field after the contacts opened as is ordinarily done in circuit-breaker design, and the strength of this coil must be many times that usually used to rupture the circuit by giving the quick start and acceleration to the arc necessary for the speed desired. The breaker in question has a total of about 150,000 ampere turns at the maximum current obtained.

The moving parts must all be as light as possible, consistent with the great strength required, so that they can be started, accelerated, and stopped in a very short space of time and distance. Even with this type of construction, it was found necessary to use somewhat high spring pressure; the spring being compressed to about 8000 pounds when the breaker was closed and ready for tripping.

A very special latch with very small tripping movement was designed somewhat similar to the hair trigger on a rifle, in connection with a special high-speed tripping coil so that about 0.001-inch movement of the plunger would trip the breaker. It will assist in appreciating the speed attained when it is noted that the breaker must be arranged so that it will not trip under ordinary load condition and must be set above the tripping point of the regular substation breaker so that it will act while the current is increasing from say three and one half times load to eight times load; current rising at the rate of about 1,000,000 amperes per second. Fig. 6 gives a very good idea of speed and limiting of current, from which it will be seen that the breaker starts to insert resistance in about 0.008 second and the load on the machine is reduced well below the flashing value in 0.02 second after the short circuit was applied.

A breaker was tested very exhaustively in connection with a 2000-kilowatt, 3000-volt, direct-current synchronous motor-generator set shown in Fig. 9, built for the Chicago, Milwaukee & St. Paul electrification, and found to give complete protection from damage or burning on short circuit when equipped with barriers shown in Fig. 5.

In connection with the test, it was found that even the speed of 0.008 second obtained would not completely protect machines from flashing on the most severe short circuit and barriers shown were designed and installed. Tests referred to with high-speed breakers were taken with these barriers, which will be described later.

It is evident that it is preferable in case of short circuit to insert resistance by a high-speed breaker to quickly limit the current to some conservative value and then open the circuit. This type of protection has been adopted as standard. All tests, investigations, etc. were based on this scheme, although some tests were taken [illegible] circuit. It was found that [illegible] greater tendency [illegible] was [illegible] through resist-

Fig. 7. High-speed, Air-cooled Fuse Holder with Magnetic Blow-out Used in Test

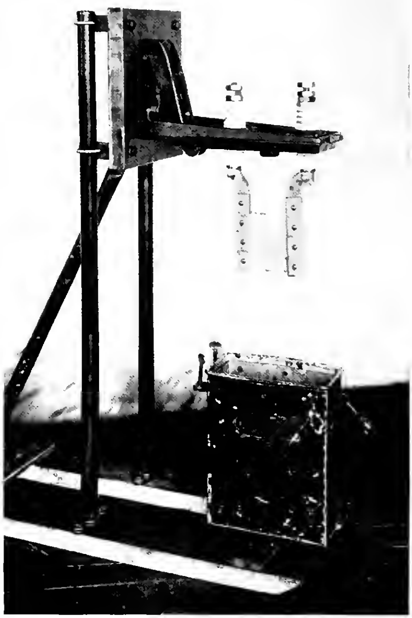


Fig. 8. High-speed, Oil-cooled Fuse Holder Used in Test

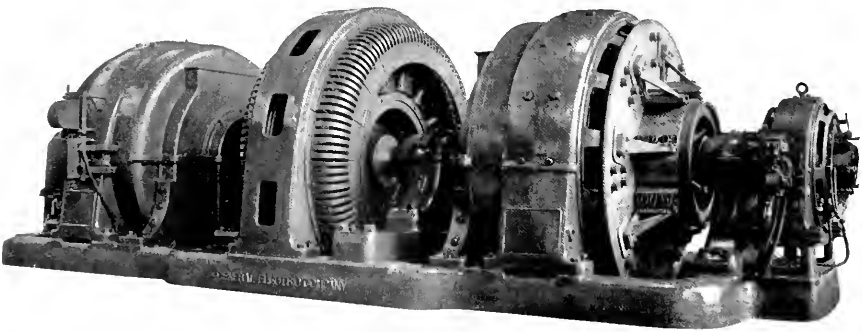


Fig. 9 2000-kw., 3000-volt, Direct-current Synchronous Motor-generator Set Before Assembly of Flash Barriers ance was inserted, reducing the load to too low a value. For the sake of convenience and comparison, all tests were made throwing short circuit on the machine without load.

Some of these breakers have been in service since early in 1917 in the substations of the Chicago, Milwaukee & St. Paul Railroad and have amply justified the faith of the railroad company and the designers, as they protect the apparatus from all short circuits experienced, although all feeders are tapped directly to the overhead trolley system immediately at the substation.

One of these breakers is installed in each of the substations connected between the negative bus of the station and the ground or return circuit, as this location gives maximum protection, and one breaker can be used for each machine or one for the entire substation, as shown in Fig. 10.

High-speed Fuse

It is evident that if a fuse could be developed that would melt at a very small increment of current above normal rating, it might be possible to obtain a speed which would limit the current on a short circuit along the same line as the high-speed circuit breaker just described.

A careful study of all available metals was made by Mr. P. E. Hosegood, who suggested using a silver fuse, and a number of silver fuses of different shapes were tried in the special fuse holders shown in Figs. 7 and 8. The oscillograph record, taken with air brake fuse and magnetic blow-out, shown in Fig. 11, indicates that a very high speed is obtained, giving excellent protection and duplicating almost exactly the speed of the high-speed circuit breaker. It was found that a short circuit could be thrown on the 300-kilowatt, 25-cycle, 600-volt synchronous converter without flashing over and with very little sparking at the brushes. The oil-immersed fuse holder without magnetic blow-out gave practically the same result, Fig. 12, the operation being slightly better as far as speed was concerned but the mechanical difficulties of replacing the fuse, etc., being greater

Reactors

Oscillograph records of short circuit on the 300-kilowatt, 25-cycle, 600-volt synchronous converter show an average initial current rise of about 1,300,000 amperes per second To protect by reactance, the amount required would depend on the rate of circuit-breaker action. With coils made of 1000 feet of 500,000 circular mil cable, wound on cable reels having an inductance of approximately 0.02 henry in circuit, this particular machine could be short-circuited without flashing when protected by a breaker opening in about 0.15 second.

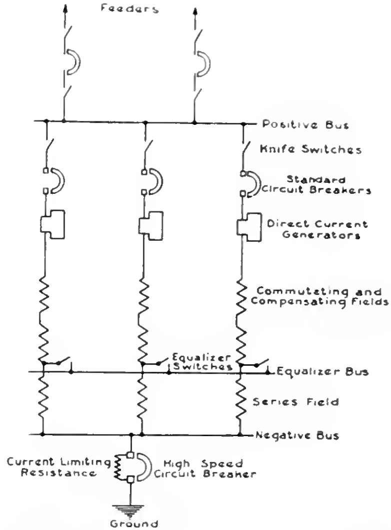


Fig. 10. Diagram of Direct-current Connections for Substation Equipped with Three Motor generator Sets Protected by One High speed Circuit Breaker Connected Across Limiting Resistance

An examination of records, Figs. 13 and 14, will show the severe duty on the circuit breaker and increase in voltage on the apparatus.

It was suggested that shunting the reactor by resistance might reduce duty on the circuit breaker The coils were shunted by 14 and by 100 ohms and it was impossible to determine from either observation or oscillograph any effect due to the resistance

The effect of an iron core in a reactor having an inductance of 0.00105 henry is shown in Fig. 15, from which it will be noted that the iron saturated at about 1000 amperes in about 0.007 seconds, after which the current rises abruptly, being limited only by the inductance of the coil as if there were no iron in its magnetic circuit The delay of about 0.007 second, due to the presence of iron in the coil, is far less than the time required for the usual breakers, now in use, to open The

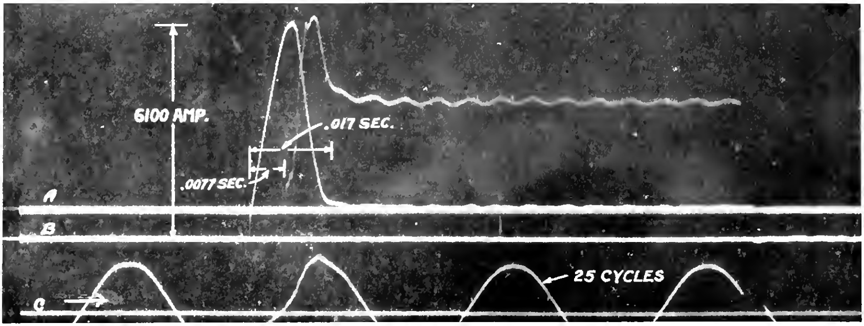


Fig. 11. Short Circuit on 300-kw., 600-volt, 25-cycle Synchronous Converter Protected by Air-cooled, High-speed Fuse. Curve A, voltage across fuse; Curve B, line current; Curve C, collector-ring voltage

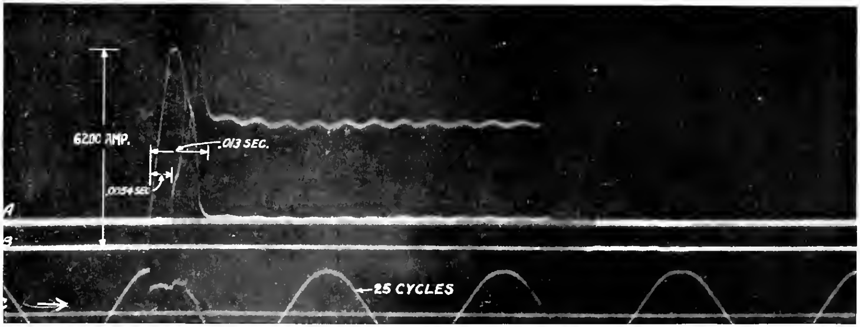


Fig. 12. Short Circuit on 300-kw., 600-volt, 25-cycle Synchronous Converter Protected by Oil-cooled, High-speed Fuse. Curve A, voltage across fuse; Curve B, line current; Curve C, collector-ring voltage

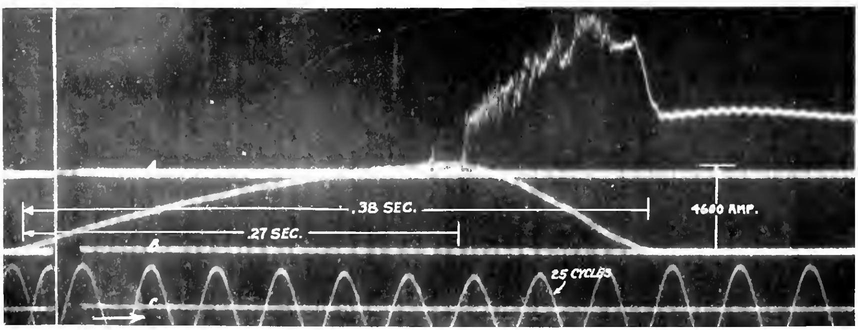


Fig. 13. Short Circuit on 300-kw., 600-volt, 25-cycle Synchronous Converter Protected by Air-core Reactor in Direct-current Circuit and Standard Circuit Breaker. Curve A, voltage across circuit breaker; Curve B, line current; Curve C, collector-ring voltage

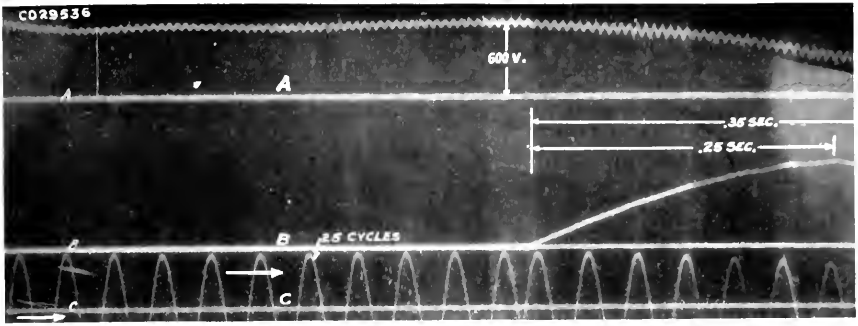


Fig. 14. Short Circuit on 300 kw., 600 volt, 25 cycle Synchronous Converter Protected by A[illegible] Re[illegible] Direct-current Circuit and Standard Circuit Breaker. Curve A, voltage across armature; Curve B, line current. Curve C, collector ring voltage.

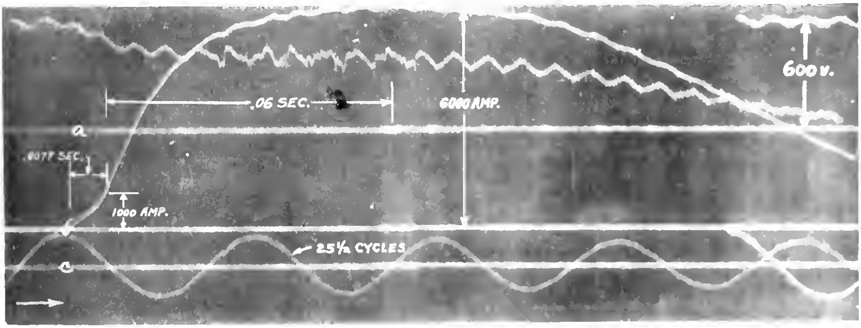


Fig. 15. Short Circuit on 300 kw., 600 volt, 25 cycle Synchronous Converter Protected by In[illegible] Re[illegible] Direct current Circuit and Standard Circuit Breaker. Curve A, voltage across the arm[illegible] Curve B, line current. Curve C, collector ring voltage.

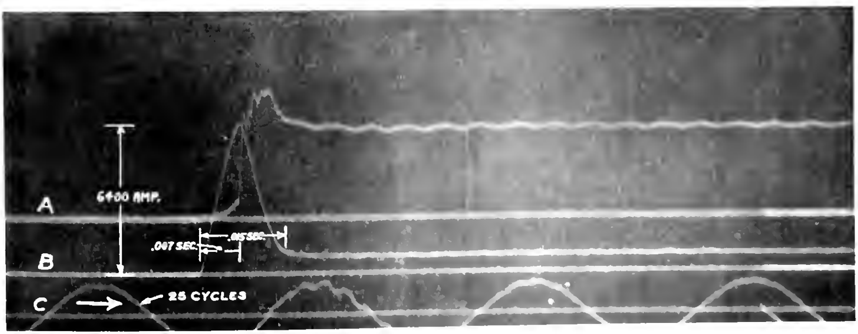


Fig. 16. Short Circuit on 300 kw., 600 [illegible] High speed Circuit Bre[illegible] line cur[illegible]

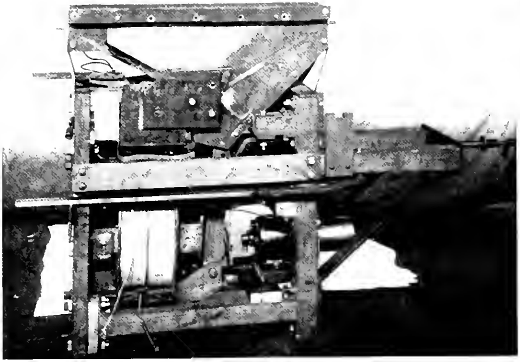


Fig. 17. Second Form of High-speed Circuit Breaker, Capacity 1500 Amperes, 600 Volts

Fig. 18. Short Circuit on 300-kw., 25-cycle, 600-volt Synchronous Converter Protected by Flash Barriers and Standard Circuit Breaker

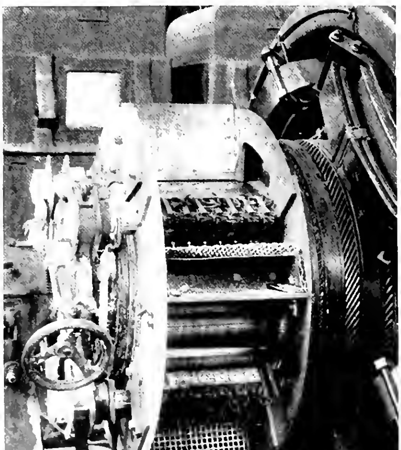


Fig. 19. Final Development of Flash Barriers on 300 kw., 25 cycle, 600-volt Synchronous Converter

Fig. 20. Short Circuit on 300-kw., 25-cycle, 600-volt Synchronous Converter Protected by Flash Barriers and Standard Circuit Breaker

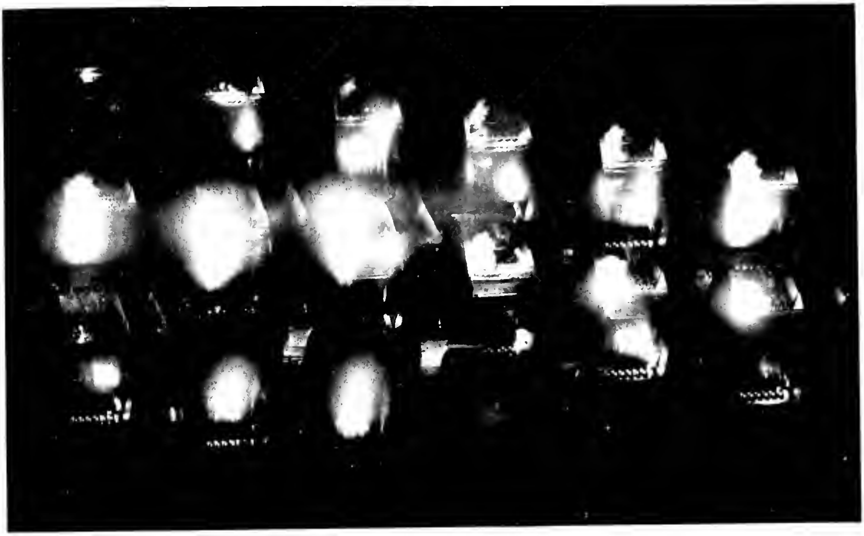


Fig. 21. High-speed Photograph of Short Circuit on 300 kw., 600 volt, 25 cycle Synchronous Converter Protected by Flash Barriers and Standard Breaker

Fig. 22. High speed Photograph of Short Ci[illegible] kw [illegible] Sy[illegible] Protected by Flash Barr[illegible] nd Stan[illegible] C[illegible] Breake[illegible]

weight of this reactor was 7 per cent of the weight of the synchronous converter, and would have to be many times larger to give protection with an ordinary breaker.

Second Form of High-speed Circuit Breaker

Mr. J. F. Tritle has more recently suggested a design for a high-speed circuit breaker which is simple and substantial in construction. This device was built as shown in Fig. 17 and test indicated that the speed was even faster than the large breaker previously described, as will be seen by comparing oscillograms, Fig. 6, on the large breaker, and Fig. 16 taken with the later breaker. This device is essentially a contactor having a laminated structure with electric holding coil and series bucking coil so that it opens when the load current reaches a value sufficient to offset the ampere turns of the holding coil. Tests on the 300-kilowatt, 25-cycle synchronous converter with this device show that a short circuit could be thrown on the machine without any tendency of the machine to flash over, and the only sparking obtained extended not over one-half inch from the brushes. Similar tests, Fig. 23, on the 60-cycle, 500-kilowatt synchronous converter showed more sparking and, although it protected the machine at times on short circuit, there were other times when the machine flashed over. When the machine was equipped with barriers, dead short circuit could be thrown on with impunity, there being no tendency to flash over and scarcely sufficient sparking to be noticeable.

This later type of high-speed breaker is a part of the more recent equipment being furnished the Chicago, Milwaukee & St. Paul Railway.

Barriers

The barriers shown in Fig. 5 in connection with the description of the high-speed circuit breaker were developed to delay time of fashover, so that the breaker would give complete protection. Such satisfactory and promising results were obtained without the breaker that it was decided to continue investigation to ascertain if it would be possible to devise barriers that would take care of all short circuits experienced in actual service.

Under certain conditions it might be desirable to supplement rather than replace appliances already installed or to protect from disturbances other than direct-current load which cause flashing. For instance, a synchronous converter could not be protected by a high-speed, direct-current circuit breaker if flashing is caused by alternating-current phase displacement. For this reason additional protection, such as barriers, to dissipate the arc when started was also needed.

Many different forms of barriers were tried on the 300-kilowatt, 25-cycle, 600-volt synchronous converter, previously mentioned. With increasing success as improvements were made to meet failures, the barriers shown in Fig. 19 were evolved. These barriers gave complete protection from flash-over or damage on short circuit. Fig. 20 shows machine on short circuit giving a good idea of flashing and protection afforded, while Fig. 21 shows clearly the small amount of flash which extends beyond the barrier.

About 65 short circuits were thrown on the 300-kilowatt, 600-volt, 25-cycle machine without burning of brushes, brush connections or rigging, or damages of any kind to commutator or machine. Oscillogram, Fig. 26, shows a record of current reaching 34 times full load and gives a good idea of the protection afforded. Many of these short circuits were applied at very short intervals, even as close as one minute apart, without failure to hold and extinguish the arc when the breaker opened the circuit.

Figs. 21 and 22 are very interesting high-speed pictures of the same short circuit analyzed by means of a special high-speed camera devised by Lieut. Chester Lichtenberg, and the successful high-speed pictures we are able to show in this paper are mainly due to his efforts. This camera made it possible to obtain as high as 24 complete pictures of one short circuit, while the best results it was possible to obtain with a motion-picture camera were two under-exposed and therefore indistinct pictures.

A little explanation is necessary to read these photographs as, due to the construction of the camera, the lower right-hand picture is the first picture of the short circuit; the next picture being the one immediately to the left, and so on to the end of the plate; the first picture at the right of the next row being the next picture in the same order and until the end of the plate and the number of rows of pictures. These pictures show very clearly the growth of the arc, disposition on commutator, and dissipation of the arc as the regular breaker opens. These permanent records eliminated the personal factors of memory and observation and showed the way for changes to give improvements in barriers Fig. 29 illustrates very clearly what happens if the machine is short-circuited without protection.

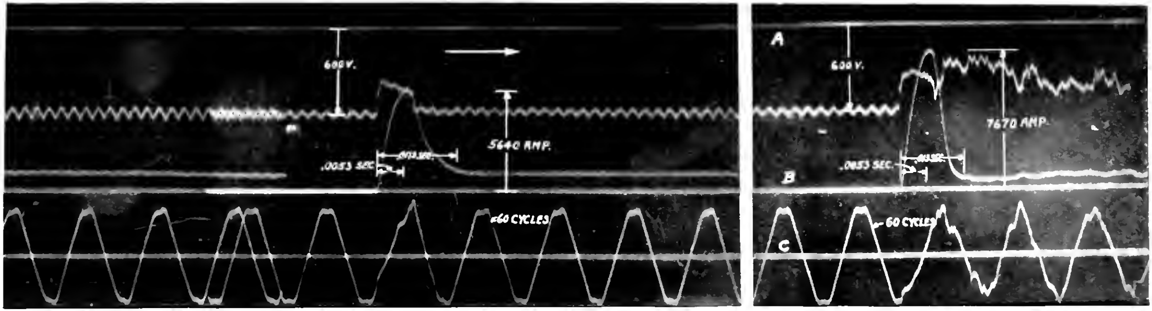


Fig. 23. Short Circuit on 500 kw., 600 volt, 60 cycle Synchronous Converter Protected by Second Form of High speed Circuit Breaker

Left hand curves
Load of 0.03 ohms

Right hand curves
Short circuit

Curve A, armature volt
Curve B, line current
Curve C, collector ring voltage

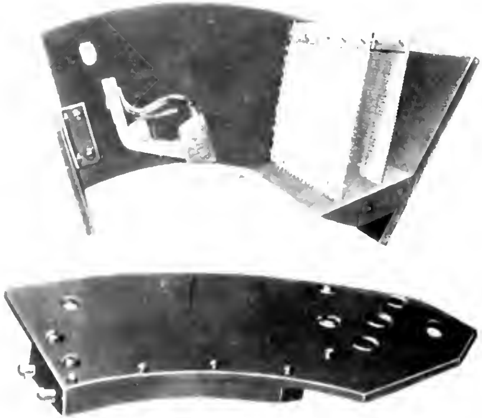


Fig. 24. Flash Barrier with Front Removed to Show Location and Construction of Arc-scoop and Wire-mesh Arc Coolers

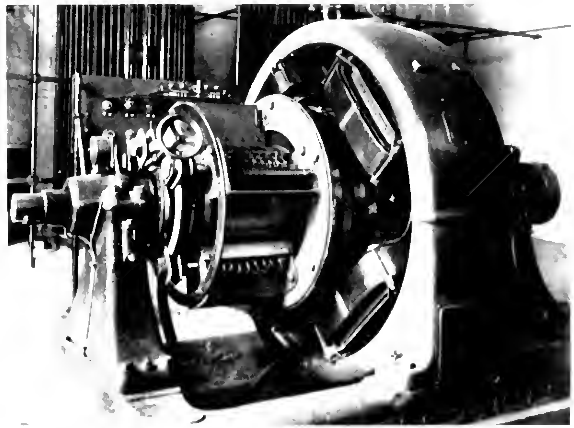


Fig. 25. 500 kw., 25 cycle, 600 volt Synchronous Converter, Installed in Automatic Substation Equipped with Commercial Form of Flash Barrier

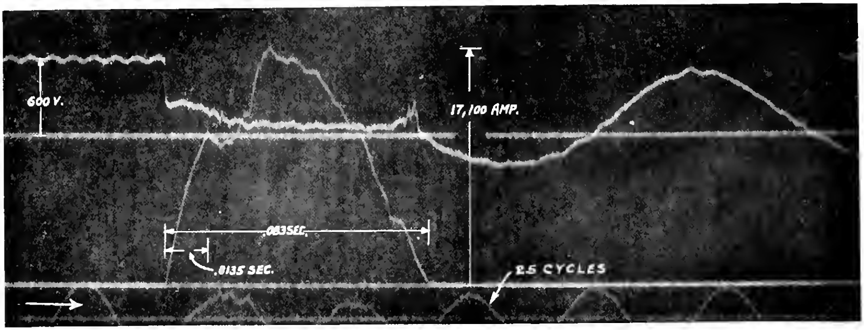


Fig. 26 Short Circuit on 300-kw., 600-volt, 25-cycle Synchronous Converter Equipped with Flash Barriers and Standard Circuit Breaker Curve *A*, armature volts, Curve *B*, line current, Curve *C*, collector-ring voltage

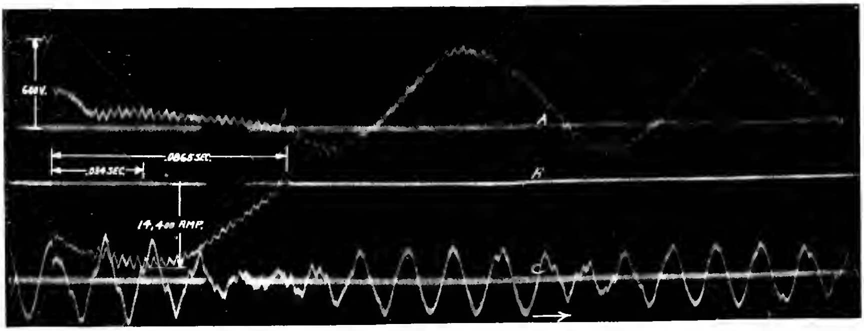


Fig. 27. Short Circuit on 500-kw., 600-volt, 60-cycle Synchronous Converter Protected by Flash Barriers and Standard Circuit Breaker after Arrangement of Brush Rigging had been Changed

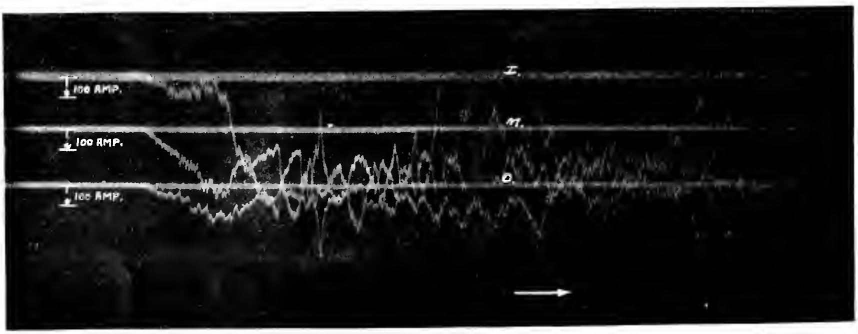


Fig. 28 Short Circuit on 50 kw., 600 volt Generator. Curve *O*, current in outside brush: Curve *M* current in middle brush, Curve *I*, current in inside brush

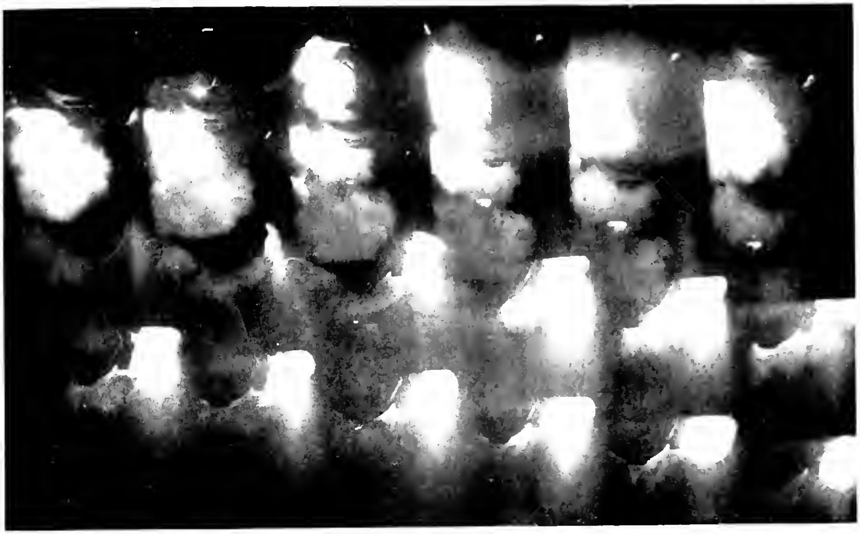


Fig. 29. High-speed Photograph of Short Circuit on 500 kw., 600 volt, 60 cycle Synchronous Converter Without Protection

Fig. 30. High-speed Photograph of Short Circuit [illegible]
Standard Circuit Breaker with Preliminary [illegible]

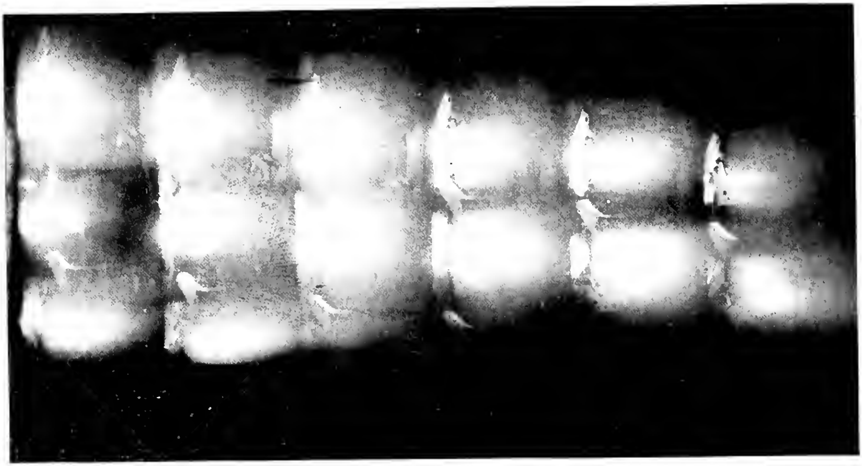


Fig. 31 High-speed Photograph of Short Circuit on 500-kw., 600-volt, 60-cycle Synchronous Converter with Flash Barriers and Standard Circuit Breaker with Preliminary Arrangement of Brush Rigging. Arc at outer end of Brush Rigging

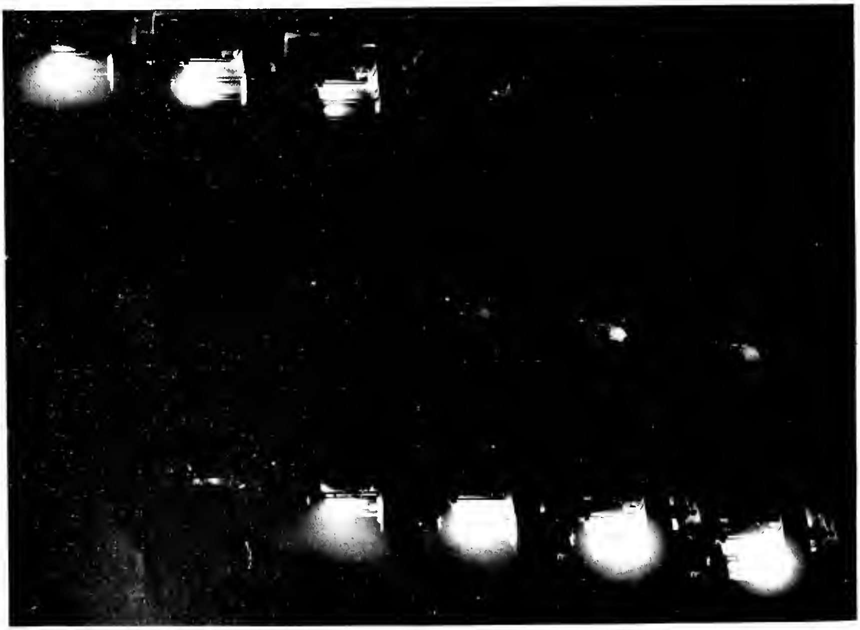


Fig. 32 High-speed Photograph of Short Circuit on 500-kw., 600-volt, 60-cycle Synchronous Converter Protected by Flash Barriers and Standard Circuit Breaker after Arrangement of Brush Rigging has been Changed. Uniform distribution of flashing

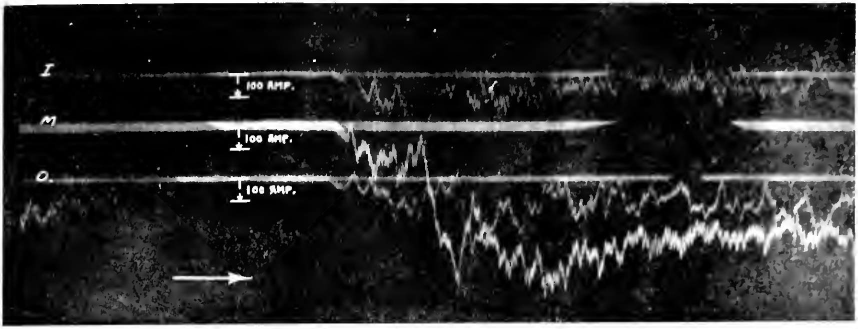


Fig. 33. Short Circuit on 50 kw., 600-volt Generator. Curve *O*, current in outside brush. Curve *M*, current
Curve *I*, current in inside brush

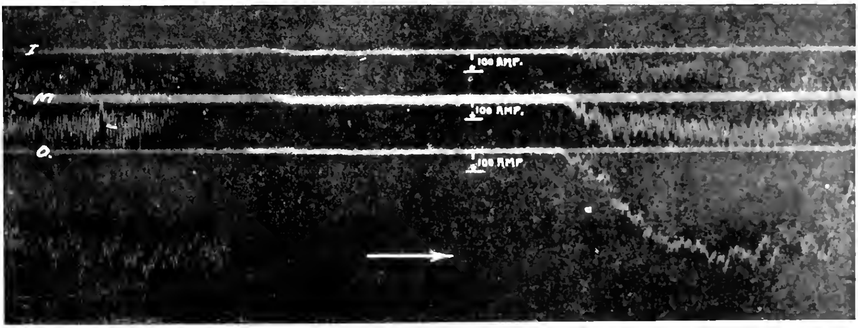


Fig. 34. Short Circuit on 50-kw., 600-volt Generator. Curve *O*, current in
brush, Curve *I*, current in inside brush

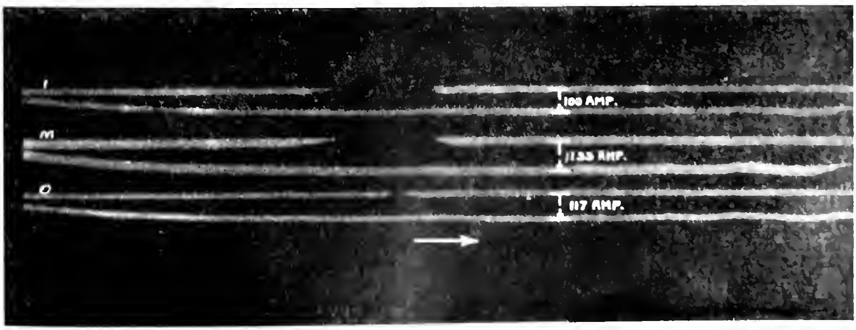


Fig. 35. Current Passed Through 50 kw

The general arrangement of a successful barrier, Fig. 25, is shown herewith.

A close-fitting box of fire-proof insulating material surrounds each set of brushes and is located so as to give a small clearance between the box and the commutator.

On the side of the box towards which the commutator rotates after leaving the brush is fastened a V-shaped "scoop," Fig. 24, of fire-proof insulating material, preferably having good heat conductivity, pointing toward the brush and having small running clearance from the commutator.

Radially above the scoop, about one inch apart, are two metal screens, one coarse and one fine mesh, through which the arc is successively forced and cooled.

It was found that a moderate amount of material is required to give the necessary thermal capacity to prevent an arc from passing beyond a screen of this kind. The scoop running very close to the commutator with narrow edge and small clearance picks up the arc from the commutator and deflects it into the arc coolers which, from their construction, allow free passage of all gases generated by the arc. The cooling and condensing of the arc reduces the gas pressure so that shields at the end of the commutator, to prevent the arc being thrown from the end of the commutator and communicated to pillow block and frame, are permissible. It will be noted from the illustrations that the commutators extend beyond the end of the barrier as it was found that the arc must be prevented from being communicated to the end of the bars.

Investigation was then transferred to a 500-kilowatt, 60-cycle, 600-volt synchronous converter, and barriers of similar type, but without continuous end shields, were tried.

Tests showed that these barriers did not give protection on short circuit although they prevented machine from flashing over on very high overload. The high-speed camera record indicated that the arc was being thrown to the outer end of the commutator for some reason causing such high gas pressure at the outer end of the commutator that the arc was blown under the barrier and the machine flashed over. Figs. 30 and 31.

The differences in performance were ascribed to differences of magnetic fields acting on the arc.

To demonstrate the effect of the magnetic field, various arrangements of connections of brush rigging were made, each to produce a different field where the arcing occurs. The results indicate that it is possible to arrange the brush rigging and connection to make a barrier, as described above, effective on practically all commutating machines and to prevent complete flashover. Figs. 32 and 27 show the effects of change in connection on arc distribution, giving the uniform distribution most favorable to good barrier performance.

Other tests were made to record the simultaneous short-circuit current in the outer, middle, and inner brushes by the oscillograph. The records in Figs. 28, 33 and 34 show typical variations of current distribution produced by different connections to brushes. The distribution of current is principally dependent on the magnetic field surrounding the brushes where the arc is formed. To show that differences of impedance have very little influence, record Fig. 35 was taken with current supplied from an exterior source with no flashing. It will be seen that current is practically the same in all brushes. With some connections the deflection of the arc can be plainly seen to follow the well-known relation of current, flux, and force, but with the more complicated connections the difficulty of determining resultant field from many sources makes it difficult to determine the direction of deflection of the arc except by experiment.

Direct-current machines for use in* automatic substations are being equipped with these barriers and short-circuit tests at the substations have been taken, indicating that they will take care of any short circuit experienced in actual service. These barriers are in operation and short-circuit tests were taken on a 500-kilowatt, 600-volt, 25-cycle synchronous converter of the Des Moines Electric Railway, Des Moines, Iowa, a 500 kilowatt, 600-volt, 60-cycle synchronous converter of the Columbus Electric Railway & Light Company, Columbus, Ohio, and a 500-kilowatt, 30-cycle, 1200-volt synchronous converter at Monteith Junction, Michigan; and other installations are now in service.

The investigations and tests indicate that if any commutating machine is equipped with barriers and the last high-speed circuit breaker described, complete protection will be given against external short circuits of all kinds so that interruption to service will not be of any greater duration than necessary for closing the circuit breaker as in ordinary overload operation.

* See paper by Taylor and Allen, A.I.E.E., "Transactions," vol. xxxiv, 1915, page 1801.

Life in a Large Manufacturing Plant

PART IX. CLUBS AND ASSOCIATIONS

By Chas. M. Ripley

Publication Bureau, General Electric Company

As all work and no play makes Jack a dull boy we naturally expect to find that the employees of a large organization have been provided with opportunities for social and recreational activities, and in this installment we describe some of the clubs and associations in which membership is limited to the men and women employees of the General Electric Company.—Editor.

Though much has been written about the electrical industry, comparatively little is generally known about the electrical fraternity. One of the factors which has contributed largely to the rapid development of the electrical industry has been the spirit of comradeship which animates and inspires the workers. This fraternal spirit manifests itself in the voluntary formation of clubs and associations all over the country. This chapter will briefly describe some of the more important clubs and associations at twelve different locations, having a total of over 33,000 members. The membership or ownership of these clubs is exclusively among the men and women of the General Electric Company.

MEN'S SOCIAL CLUBS AND ASSOCIATIONS

	Member
Quarter Century Club	1198
Edison Club at Schenectady	600
General Electric Club of New York	170
General Electric Club of Boston	130
Firemen's Association at Schenectady	130
Firemen's Association at Lynn	108
Thomson Club at Lynn	100
Mazda Club at Harrison	175
Coin and Stamp Club at Lynn	47
Sprague Club at Bloomfield	

The Edison Club

The Edison Club was formed in 1901 as a result of a petition which was signed by 183 college graduates who were taking the test course at the Schenectady Works. Today there are over six hundred members, mostly graduates from American and foreign colleges. These young men have all pursued the same studies, have undergone the same training in the test course, and have lived the same life while being initiated into the electrical industry. The "camaraderie" exists not only between the younger members, but the various social and athletic activities offer opportunities for the student engineers to be brought in contact with many of the officials and engineers of the Company. The Club has a real "University Spirit" and contributes largely toward making the life of the test man in Schenectady not only wholesome but happy. The six photographs illustrate the three club buildings on a plot 90 ft. by 369 ft., and suggest good times of various kinds.

Among the aquatic sports canoe racing leads, and the club is affiliated with the American Canoe Association and participates in the races of the "Big League" in Schenectady and other neighboring cities. A score or more of silver cups and other trophies have been won, and the Edison Club boys stand for all that is good, clean, fair, and manly in the realm of aquatic sports.

One hundred and twenty-five members of the Club ranging from the newest test man to the heads of departments in the general offices have formed the highly successful Intercollegiate Bowling League which meets regularly throughout the year.

Fencing, boxing, bag punching, hand and medicine ball, basketball, and tennis are among the other sports.

Members who are musically inclined have formed an orchestra, mandolin club, minstrels and brass band.

Each year the members of the Club who are far away from home gather together at an elaborate Christmas dinner at the Mohawk Golf Club. Addresses are given by Dr. Chas. P. Steinmetz, Mr. E. W. Rice, Jr., and other officials of the Company.

A salaried superintendent is in charge of the Club.

The Thomson Club at Lynn

This Club was organized largely for the benefit of the college men who entered the organization, and has a normal membership of one hundred.

The photographs show interior and exterior views, including one of the many sleeping

Fig. 1. The Edison Club at Schenectady is the Rendezvous for the Test Men from Technical Colleges and Universities from all Over the World. It might well be called the "Cosmopolitan University Club."

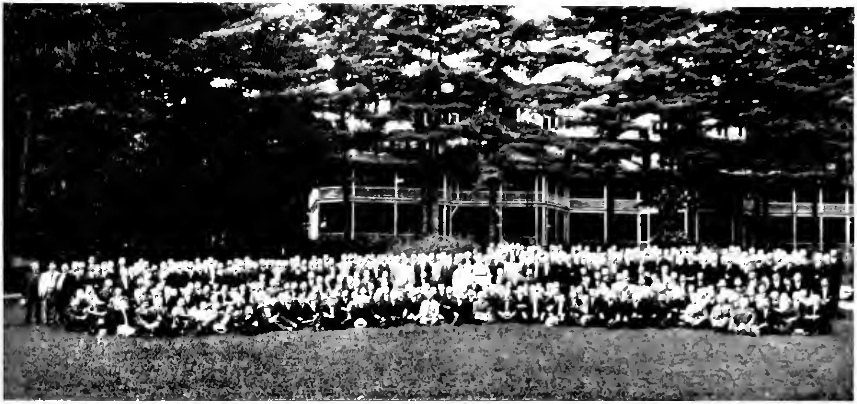
Fig. 2. Edison Hall Contains an Assembly Hall, Seating Four Hundred People; Four Bowling Alleys, Shower Baths, Motion-picture Machine, and Kitchenette. The meetings of the A.I.E.E. and other engineering societies are held here and by removing the portable chairs a beautiful ballroom floor is available for dancing

Fig. 3. Reading Room of Edison Club at Schenectady. The Club is used night and day by the test men. Pool and billiard tables, card room, and library are in great demand

Fig. 4. Bowling Alleys of the Edison Club with Their Automatic Pin-setting Equipment. Intercollegiate bowling teams have rousing times in their matches.

Fig. 5. The Concrete Boathouse on the Banks of the Mohawk River in the Rear of Edison Club and Hall. A double track is provided for running the 200 canoes in and out of the fireproof boathouse

Fig. 6. One of the Regattas of the American Canoe Association. The Edison Club Team has won many trophies in meets on the Mohawk River and elsewhere



Schenectady Section, Quarter Century Club, at Annual Outing

Lynn Section, Quarter Century Club

The Foremen's Association at Schenectady on One [illegible] baseball games, and other sports are [illegible] rooms which accommodate twenty-five of the members.

Mazda Club at Harrison

With sleeping accommodations for twenty members, this club includes in its membership superintendents and department heads as well as engineers. Practically thirty-five members take their meals here. The equipment includes three billiard tables, bowling alleys, and two sets of tennis courts on the property. The members have also formed a club orchestra.

The Quarter Century Club

The General Electric Quarter Century Club was organized in 1914 and its membership is limited to those who have spent a quarter century or more in the employ of the Company. The membership is divided as follows:

Schenectady	653	Pittsfield	17
Lynn	318	Sprague	12
District Offices	114	Erie	5
Fort Wayne	52		
Harrison	27	Total	1198

The total years of service rendered by the 1198 members reaches the staggering figure of considerably over 33,000 years; and if expressed in the terms of one man's life, would extend from 11,000 B.C. to 22,000 A.D.

The Club has annual outings, banquets, and athletic events. The button worn by the members is attractive and is no doubt familiar to tens of thousands of workers in the electrical industry.

WOMEN'S SOCIAL CLUBS AND ASSOCIATIONS

	Members
Women's Club at Schenectady	250
Girls' Gymnasium at Lynn	40
Women's Club of New York	90
Girls' Minstrel Club at Pittsfield	100
Elex Club at Fort Wayne	75

General Electric Women's Club

The General Electric Woman's Club at Schenectady has a beautiful clubhouse, of which four pictures are shown. The cultural studies, the social events, and wartime activities of this Club are the admiration of all women and men who have had the opportunity of being brought in contact with them.

The equipment includes dining-room for daily luncheon and dinner, sleeping rooms, library, piano, victrola, etc. Tennis, canoeing, picnics, and corn roasts are popular in the summer, and the glee club, dancing classes, parties, recitals, and lectures are chief among the winter entertainments. Wednesday and Sunday the members may invite their men friends. A competent steward and stewardess are in charge of the clubhouse.

Other Women's Clubs

The Gamma Epsilon Society at Harrison, the Elex Club at Fort Wayne, the General Electric Women's Club at New York, and the yearly get-together of the girls in the San Francisco office are typical of the club spirit which exists among the girl workers.

The Girl Minstrels at Pittsfield, with a chorus of twenty-eight, have attracted considerable attention at their two public performances. Songs, dances, jokes, tableaux, and male impersonations were intermingled on these occasions.

VACATION CLUBS

	Members
Girls' Vacation Camp at French Point, Lake George	500
Camp Claverack at Association Island, Lake Ontario	1000
Camp Nela, Cleveland	270
Camp Edison	115
Camp National	110
Marshall Outing Club at Harrison	61

Girls' Vacation Camp

The fascinating kodak views of the General Electric outdoor girls are sufficient to suggest the good times which approximately five hundred girls enjoy annually at Lake George. French Point Camp comprises forty-two acres, and is equipped with private dock, boathouse, icehouse, running water, rainproof tents, unsinkable row boats, motor boats, piano, victrola, rustic smokehouse, Dutch ovens, rustic seats, basketball and volleyball courts, hammocks and swings, games, and books. On rainy days they gather around the cobblestone fireplace of the "rendezvous" and in the evening dance on the piazza.

Delightful trails lead up into the mountain nearly 2,000 feet above sea level; a swimming instructor and physical director look out for the girls' health. Any girl employed by the Company in the factories in nine cities or in any of the district offices may spend her vacation on this beautiful lake at a cost of less than one dollar a day.

Camp Claverack

Camp Claverack covering 65 acres is located on Association Island, Lake Ontario.

Fig. 7. The Thomson Club in Lynn Fills the Same Needs as the Edison Club in Schenectady. There is a meeting room, dining-room, library, piano, etc., downstairs. It is an easy walk from the factory to the Club house

Fig 8 Meeting Room of the Rifle and Revolver Club. This, together with the Girls' Gymnasium, the Bowling Club, the Apprentice Alumni Club, and the Foremen's Association, are all located in the Recreation Building which is also Headquarters for the Athletic Association

Fig. 9. Sleeping Rooms are Provided at the Thomson Club for the Accommodation of 25 Members. Most of these young men are college graduates who are getting their practical training in the shops of the Company

Fig 10 Girls' Gymnasium at Lynn, Attended Regularly by Forty Girls The equipment and instructor are provided by the Company and there is a rest and lunch room nearby

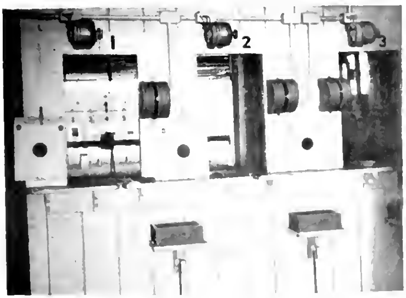


Fig. 11. Rifle Range Equipped with Electrically Driven Targets which Permit Contestants to Change Targets Rapidly Without Anyone Serving in Pits. Electric motors whisk the targets back and forth

Fig 12 Alleys of the Bowling Club at Lynn. L[illegible] ship games are held here and the Club [illegible] won in competition with other local teams

Fig. 16. The Women's Club Nestles Amid a Wealth of Foliage and Shrubbery. The young business women find rest after the busy day in this oasis of industrious Schenectady

Fig. 17. It is a Handsome Building, Formerly the Residence of One of the Officials of the Company. The property extends down to the Mohawk River

Fig 18. Library at the Women's Club with Corner of Dining-room in Background. Luncheon and dinner are served daily

Fig. 19. The Girls at French Point Camp Sleep in Twenty-five Rainproof Tents with Wooden Floors and Two Cots Each. Each tent commands a view across Lake George

Fig. 20 The Camp Lies at the Very Foot of Tongue Mountain Which Rises About 1800 Feet Above Sea Level A hike up the mountain, with a picnic lunch on the top makes a good day's sport

Fig 21. Meeting the Boat at the Private Dock of the Girls' Camp. Since the boats stop at the dock the girls are landed right IN the Camp, thus making the journey pleasant and inexpensive

It is owned by the "Association Island Corporation" composed of men prominent in the electrical industry—nearly all of whom are employed by the General Electric Company. The open-air life is available not only to the men of the Company, but also to their families and friends. Edison and Camp National are also located on Association Island.

Camp Nela

Camp Nela at Cleveland, Ohio, is an electrical community for summer vacations and week-end trips. The camp contains swimming pool, ten tennis courts, two clubhouses, four bowling alleys, football field, grand stand, basketball court, gymnasium, library, auditorium, kitchen, two pianos, three victrolas, rifle and revolver range, lockers, and shower baths. The architectural features of the camp suggest the Roycrofters' art, especially the two outdoor rustic amphitheaters.

ATHLETIC CLUBS AND ASSOCIATIONS

	Members
Athletic Association at Schenectady	300
Nela Athletic Association at Cleveland	400
Athletic Association at Erie	125
Rifle Club at Lynn	125
Rifle Club at Erie	10
Bowling Club at Schenectady (Shop League)	200
Bowling League (Edison Club)	125
Bowling Club at Lynn	200
Bowling Club at Erie	20
Football Club at Lynn	50

The General Electric Athletic Association

To attend an Athletic Association field day is to witness an afternoon of sport which will compare favorably with many inter-collegiate events. The equipment of these athletic associations in general include a clubhouse with lunch room, bowling alleys, training quarters, lockers and shower baths, pool and billiard tables, basketball court, gymnasium, library, auditorium, meeting rooms with piano and victrola, and also a rifle and revolver range, basketball diamond, racing track, athletic field, football field, cricket field, tennis courts, and grand stand. Many members of the athletic teams are college men and it has been found that the college man is pretty evenly matched against the shop worker in running, jumping, and other track and field events.

The bowling, baseball, and football teams and rowing crews in some of the cities are local champions, and they are the proud possessors of many trophies.

These associations are practically self-sustaining with small annual dues.

At the Lynn Works an entire building is appropriated for athletic and social activities. It is known as the "Recreation Building" and is available to any club or society that may apply for quarters in it.

MUSICAL CLUBS

	Members
Schenectady Band	50
Fort Wayne Band	35
Pittsfield Band	28
Erie Band	18
Coupler Glee Club at Erie	128
Chorus Club at Erie	40
Glee Club at Lynn	32

The Bands

It is a familiar, but none the less inspiring, event when the stirring airs of martial music reverberate between the great buildings of the General Electric factories. The brass band welcomed Secretary Daniels and Governor Whitman at the Schenectady Works during the present year; the Liberty Loan parades are always headed by the General Electric Band; the summer concerts are regular events in many of the factories; and many city parades and meetings engage these bands for special occasions.

The Erie Chorus and Minstrel Club last February gave two performances to "SRO" audiences at the Park Opera House. The string quartet, black-faced comedians, musical, and fancy dancing numbers vied with the Japanese Girls, the Soloists, and the the tableaux.

DEPARTMENTAL ASSOCIATIONS

	Members
Foremen's Association at Schenectady	225
Foremen's Association at Erie	225
Draughtsmen's Association at Schenectady	400
Electro Technique Club at Fort Wayne	400
Cost Accountants' Association at Schenectady	123
Apprentice Club at Schenectady	112
Apprentice Club at Lynn	80
Order & Stock Department Association at Schenectady	56
Power & Mining Department Bowling Club at Schenectady	48
Power & Mining Department Girls' Bowling Club at Schenectady	13
Foreign Department Bowling Association at Schenectady	20
Building-Maintenance Department Club at Erie	20

Whether chiefly for education or recreation, these Departmental Associations add much to the spirit of co-operation in their several spheres of influence. The Apprentice Clubs have an annual outing and picnic, others have banquets, motor trips, clambakes, amateur theatricals, etc.

Fig. 22. The Pittsfield Band in their Smart Uniforms not only give Outdoor Concerts in the Warm Weather but are Engaged to Lead and Participate in all Big Parades and Similar Municipal Celebrations

Fig. 23. Baseball Diamond, Track, Field and Grandstand of the Athletic Association at Schenectady. Baseball, football and other contests are held at frequent intervals during the spring and summer

WAR GARDEN CLUBS

	Members	Acres
Schenectady War Garden Club	1100	95
Erie War Garden Club	250	55
Fort Wayne War Garden Club	118	6.5
Pittsfield "Allen Farm"	300	37
N.E.L.A. War Gardens at Cleveland	125	4.5

Officials, engineers, foremen, mechanics, and electricians—all put their hand to the hoe and spade in this patriotic, economic, and health-giving activity. Motor ploughs and harrows prepared the soil in advance so as to lighten the preliminary work, and sheds were provided for storing the garden tools overnight.

The effect of the new daylight-saving law in lengthening the playtime after working hours, will doubtless be taken advantage of during the coming season by the amateur gardeners. As early as March, 1918, 1,000 applications had been received at Schenectady alone for garden plots to be cultivated during the coming summer.

SIX MUTUAL BENEFIT ASSOCIATIONS

The six Mutual Benefit Associations, which were described in the December Review, with a total of almost 23,000 members, afford health, life, and accident insurance for an average of nine cents per week. Field days, picnics, and theatrical entertainments play a double part in furnishing recreation and in aiding the finances of the associations. The membership is distributed as follows:

	Members		Members
Schenectady	9460	Fort Wayne	1205
Lynn	7408	Erie	1150
Pittsfield	3052	Sprague	400

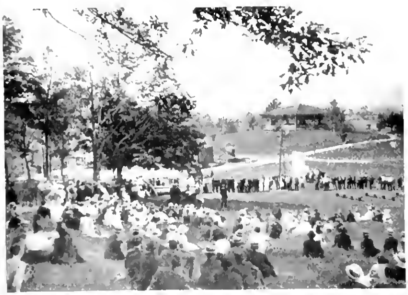


Fig. 24. Field Day of Athletic Association at Pittsfield in the Berkshire Mountains. These events are always largely attended and the athletes lustily cheered

Fig. 25. Tennis is a Popular Game Among the Members of the Schenectady Athletic Association. The courts are less than ten minutes' walk from the General Electric Works

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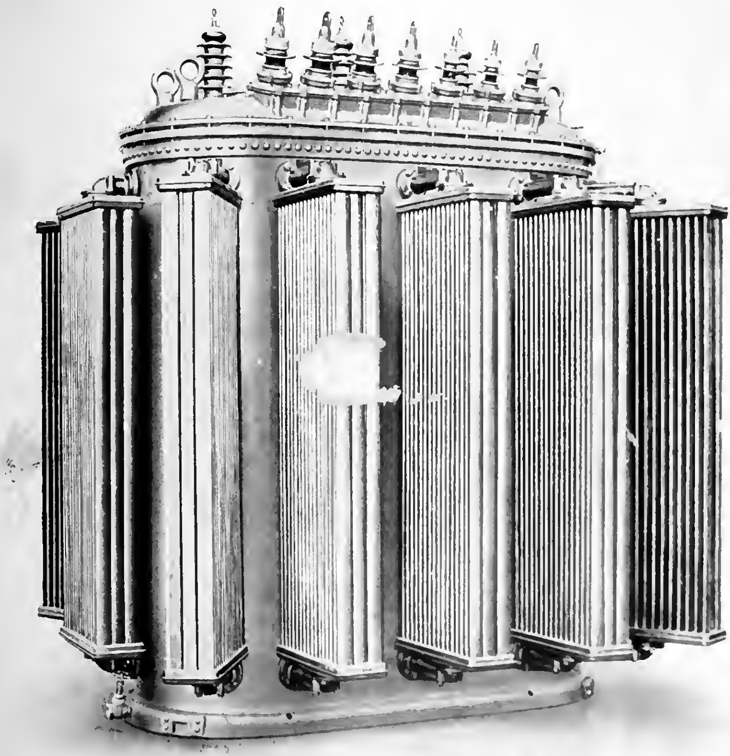

A SELF-COOLED, RADIATOR-TYPE, 5000-KV-A., 3-PHASE, 60-CYCLE TRANSFORMER HAVING TWELVE TUBULAR RADIATORS SO ARRANGED AS TO OCCUPY THE SMALLEST AMOUNT OF FLOOR SPACE. Page 556

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE — Editor, JOHN R. HEWETT — Associate Editor, B. M. EOFF — Assistant Editor, E. C. SANDERS

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CONTENTS

An instance wherein fuel is conserved by the substitution of electric for steam drive of a mine hoist. The installation is the largest induction motor-driven mine hoist in America, the motor being rated at 1800 h.p. The disconnected steam engine is shown at the right

THE EFFICIENT USE OF FUEL

Because of the abundance of fuel in years past and the lack of effective restraints to its unlimited use, our fuel users have failed to remove or repair inefficient heating and power apparatus and to replace uneconomical systems of operation. Consequently, our coal mines and oil wells have had to produce an unnecessarily large quantity of fuel, and our transportation systems have been overburdened with its conveyance.

Unprecedented difficulties in transporting this vast amount of fuel culminated last winter in the issue of a Federal edict which so suddenly and drastically limited the use of fuel as to astound fuel users. The coming of the warm weather of spring and summer has relieved the tenseness of the situation—but only temporarily—for we are informed that we shall have to prepare for a fuel shortage of 100,000 tons this coming winter, an amount double that of last winter.

For over a year we have been running in the GENERAL ELECTRIC REVIEW a series of articles under the title, "Methods for More Efficiently Utilizing our Fuel Resources," in which our wasteful methods of burning fuel and our inefficient systems of utilizing its energy are condemned, and constructive programs are proposed for the more intelligent use of our fuel resources.

To correct our extravagant use of fuel, the first and most obvious measure is to reduce the amount consumed by eliminating the waste that results from careless and inefficient operation.

The next progressive measure combines the relief of our transportation facilities and the conservation of our best fuel by the use of local low-grade fuel instead of distant high-grade fuel. The thorough dependence which we as a nation have placed upon high-grade fuel has been requiring that our railroads carry this grade of coal long distances into districts possessing commercially usable low-grade deposits, and that they haul empty cars back to the starting point for additional loads. Fortunately, investigation into the production and methods of utilizing low-grade fuels and developments along these lines have demonstrated that the use of such fuels does not entail a sacrifice, for they may be made to afford economies and conveniences in operating our locomotives, power plants, and ships that were not possessed previously.

It will not be sufficient, however, to accomplish only the conservation of the heat and mechanical energy of our fuel; we must also devote ourselves actively to the recovery of the by-products on an extensive scale. The principal fields for this endeavor lie in the coke, producer-gas, and oil industries.

Another great fault in our present methods of utilizing our fuel resources lies in our comparative neglect to develop our available water power fully. The seriousness of this omission should be apparent when one realizes that every horse-power hour of water power which is not utilized can never be reclaimed, while on the other hand every ton of coal in the ground remains good for use at any time. Also, the consumption of water-generated power will relieve our already overtaxed transportation systems from the task of conveying the equivalent in coal. While the harnessing of our available water power is a stupendous task and will require years of development, the sooner and the more energetically it is prosecuted the better. For example, the electrification of the Chicago, Milwaukee and St. Paul Railway and the substitution of water power for coal and fuel oil has saved approximately 250,000 tons of coal and 450,000 bbl. of oil in one year, and at the same time has immensely improved the railway's service.

Because of the geographical conditions met in most water-power developments, long-distance transmission is necessary. The successful solution of the electrical transmission problems encountered in hydro-electric developments has brought about many long-distance transmission systems of steam-generated power. The logical evolution in the development of these two sources of power will lead to the establishment of immense interconnected transmission networks fed by hydro-electric stations situated at natural and artificial waterfalls, and by steam-turbine stations located in the coal districts.

With such a co-operative scheme of operation for the economical generation and efficient distribution of power and with suitable restrictions to the supplementary use of all kinds of fuel, the outlook to our future fuel situation should be bright.

A Review and Forecast of the Electrical Industry

Presidential Address, Annual Convention A.I.E.E., Atlantic City, June 1918

By E. W. Rice, Jr.

After a few introductory remarks on the value of the A.I.E.E. to its members, and to the nation in its present crisis, Mr. Rice discusses some phases of the industry which are of special significance just now, and that consequently have received a great deal of consideration from the fraternity. The matters of economy and efficiency are paramount, as they bear directly on the questions of invested capital and fuel conservation. The interconnection of electric systems is a big factor in this respect. Reference is again made to the advantages of railway electrification and the great saving in coal that would be effected by the electric operation of our trunk line railways. The work of the electrical engineer in reducing the amount of material and labor necessary to produce a given result, with the consequent progressive reduction in cost of electric apparatus, largely accounts for the phenomenal growth, prosperity, and present commanding position of the electrical industry.—Editor.

Electrical engineering now covers such a wide field of scientific and technical activities that your President is presented with an embarrassment of riches in the attempt to select a subject for his address. He has, therefore, decided not to confine himself to any one feature of our Society's work, but to pick out here and there a few of many items to talk about which seem of present interest and importance.

It is a pleasure to call your attention to the fact that we have added 1235 members of all classes during the year, our total membership being now 9370. This is a most encouraging result in these times of stress and change.

The American Institute of Electrical Engineers is a national asset of increasing value to its members and to the nation. Every person who has the necessary qualifications should identify himself with the Institute, not only for the great benefits which he personally will receive, but in order that the usefulness and power of the great army of electrical engineers may be increased and rendered more available for the highest and most efficient service to our country and to the world.

The engineer is the hope of the nation, not only now, when we are at war, but even more so in the future in the days of reconstruction following the great peace. The engineer may perform valuable service when working alone, but his usefulness and power is manifestly greatly increased when acting in co-operation with thousands of his brothers.

The Institute is not only a democracy but is a democracy of educated men, and such men have a heavy responsibility to society at present and will have in the future. They should be leaders and exemplars for those who have not been so fortunate as to have enjoyed their opportunities. The Institute needs its members and the members need the Institute, that the electrical engineer may fulfill his high destiny.

That the work of the Institute is of the highest quality is evidenced by the character of its meetings, its papers and discussions, and the splendid work of its various committees. Its value and usefulness have increased every year of its existence, and it should continue to gain in strength and usefulness because its methods are in accord with the spirit of the times.

But in order to accomplish this desirable result, it must continue, as at present, to be representative of the electrical engineering profession of the country and, therefore, must continue to expand its membership. This growth will bring with it problems inherent in all great institutions, democratic or autocratic, but I have confidence that all difficulties will be met successfully for the reason that the members of our profession are trained in the scientific viewpoint and methods of solving problems.

In the early days, the progress of the electric science and arts was so rapid that it was relatively easy to find each year plenty of material for a review. Progress has continued and will continue, but naturally decided tendency to saturation is shown in many directions. In some instances, this saturation can be demonstrated to be due to the fact that limits of perfection have been so closely approached that little remains of possible accomplishment. In other instances the slowing up is due to lack of knowledge, or, especially at the present time, to lack of workers, such workers having been diverted to the work imperatively needed to secure us against the attack of our enemy on the foundations of our existence.

There has been no material improvement for several years in the matter of efficiency in electrical units, such as dynamos, motors, transformers, etc. The efficiencies stated in Past-President Lincoln's address, in 1915, still remain almost exactly of the same values, and for the reasons which he so clearly pointed out.

The efficiency of conversion of mechanical into electrical energy—or the reverse, of electrical into mechanical energy—is still about 90 per cent, in the average case, under practical conditions of operation; the efficiency reaching as high as 97 per cent or 98 per cent in the most favorable cases with large units, and falling below 90 per cent in unfavorable cases, or in small units. The efficiency of conversion of electricity from high to low potential, as in transformers, also remains substantially the same, reaching as high as 98+ per cent in the largest units.

It is obvious, as Lincoln pointed out, that no material change can be expected where such practical perfection has been reached.

The conversion of mechanical power of falling water into electrical energy by our water wheels and electric generators has increased from about 87 to 90 per cent in the largest units of 40,000 h.p. This represents about the limit which may be expected.

In the field of thermo-dynamic engines, represented largely by the steam turbo-generator unit, some improvement has been obtained. Lincoln stated that 75 per cent of Rankine efficiency had been obtained in some large modern steam-turbine units in 1915. This has now been increased to about 80 per cent in the largest units of 35,000 to 40,000 kw., and 75 per cent is quite common practice even in such moderate sized units as 10,000 kw. This improvement, while not large, is doubly important because of the great increase in the cost of fuel. It has been realized mainly by bringing the practical design more nearly in accord with the theoretical, by increasing the number of stages or processes of steam extraction, by reducing various losses, and by improving many details which when properly looked after make, in the aggregate, gains of practical importance.

Increasing the initial pressure of steam and lowering the terminal pressure, by better condenser arrangements, have also contributed to improvement, as they enable an increase in the range of temperature to be utilized. This makes possible better thermal efficiencies, even with the same per cent of Rankine efficiency.

The following information illustrates the improvement in efficiency of turbo-electric units beginning with the first 5000-kw. unit installed in this country, in 1903, and continuing up to the close of 1917:

Year	Size Kw.	Steam Conditions: Steam Pressure, Lb.	Superheat Fahrenheit Deg.	Back Pressure, Inches	Pound Per Kw-hr.	Per Cent Rankine Efficiency
1903	5,000	175	0	2	24.00	37.8
1908	14,000	200	125	$1\frac{1}{2}$	13.50	66.1
1911	20,000	235	100	$1\frac{1}{2}$	13.20	67.0
1913	20,000	200	200	1	10.74	75.9
1916	20,000	250	250	1	10.00	76.5
1917	35,000	230	200	1	10.14	78.7

It is gratifying to note that a per cent of Rankine efficiency of approximately 80 per cent has been reached. This progress reflects great credit upon the designers of turbo-electric machines and is a record of achievement found only in electrical development.

Concurrently with this improvement in the turbo-electric machines, great advances have been made in the design and operation of steam-producing devices in the boilers and in the auxiliaries and in the other features of the modern power station. As a result, the thermal efficiency has been rapidly improved. The thermal efficiency to which I refer may be stated as the ratio of the total energy produced at the terminals of the generator, to the total energy in the fuel burned expressed as a percentage. It takes account of all losses from the coal under the boiler to the electricity at the dynamo terminals. It is the ratio of the heat units equivalent to one kw-hr. divided by the similar heat units in the fuel consumed to produce one kw-hr. at the generator terminals.

This thermal efficiency is, after all, to the electrical engineer, the most important measure of progress. It measures the advance in station fuel economy, and, as stated, many factors in addition to the improvement in turbo-generators have contributed to the result. Thermal efficiency must thus be used to express the results of a single unit consisting of turbine-generator, with its bank of boilers and other accessories, or it may be used to designate the combined result of all the units in a given power station.

The progress in the case of a combination unit, i.e., turbo-generator, with its boilers, auxiliaries, etc., has been as follows:

Year	Size of Unit Kw.	Per Cent Thermal Efficiency
1903	5,000	10.15
1908	14,000	15
1913	20,000	18
1917-18	35,000	21.6

For comparison, I may state that large gas engines in steel mill practice, under best test conditions, show 25 per cent thermal efficiency, but in actual operation an efficiency higher than 18 to 20 per cent is rare.

High compression oil engines of the Diesel type, driving electric generators, realize 25 to 26 per cent thermal efficiency when new, but are difficult to maintain at such efficiency.

The figures given must not be confused with the much higher thermal efficiencies often quoted for gas and oil engines, which refer to indicated horse power and not to electrical output.

The steam turbo-electric unit has not reached its limit of thermal efficiency. Calculations show that, with pressures of the order of 500 lb. gauge, a thermal efficiency of 26 per cent should be easily realized. For any further substantial improvement we must look to new methods, such as the use of two fluids, for example mercury and steam, as planned by Mr. W. L. R. Emmet. This method is still under development but its progress has been hampered by the pressure of war work.

As a matter of interest to electrical engineers, I may say, parenthetically, that the steam turbine in this country owes its existence and development almost entirely to the electrical engineer; and this is not surprising as the electrical engineer was familiar with the advantages of rotary machines and, perhaps it is not too much to say, prejudiced in their favor.

While, as stated, the efficiency of electrical units reached about its limit some years ago, those familiar with electrical engineering development are aware that progress has been made and is still possible in the generation, transmission, and utilization of electrical energy. The struggle for improvement in efficiency has been transferred from the unit to the aggregate, called the system. We cannot have a system of maximum efficiency without units of maximum efficiency, but individual units of highest efficiency do not, of themselves, insure that the system upon which they are used will be of the highest efficiency; so progress has been made in the direction of improving the system economy or system efficiency.

To obtain the highest efficiency in practical operation, the element of time enters as a powerful factor. Our conception of efficiency should not be limited to a consideration of the relation between the instantaneous value of available heat units in coal and the electrical units produced at the point or points of consumption, but should consider the relation between the total number of heat units in fuel consumed in a given time, say 24 hours, to the total number of electrical units produced and used in the same time. The attempt to improve the efficiency of the system has shown the necessity of utilizing the generating units and transmission and distributing systems for the maximum possible time.

This has led to the study of such questions as load-factors of generators, of stations, and of the system as a whole, to the study of the diversity-factor, to the reduction of idle currents in alternating-current systems by the use of synchronous condensers, and to means for the reduction of the constant and no-load losses in all machinery, in transformers, etc.

The resulting improvement has been effected, not only by changes in designs of the units themselves, but also by their method of use, based upon recognition of the fact that the elimination or reduction of the losses at light load will greatly improve the total efficiency, especially when the time of use of the apparatus under load is a small part of the total time.

Automatic substations for transformers and rotary converters have come into existence; different power houses of the same system have been tied together electrically; transmission lines of different systems have been inter-connected, so that the units may be usefully employed for the maximum period, or lie idle or unloaded for the minimum time.

This general development has led to marked improvement in total energy efficiency, represented by the amount of fuel burned per electrical unit sold or utilized, and has also reduced the cost of operation and the charges for investment. There is still room for continued improvement in this direction and the progress will be rapid due to the pressure for maximum efficiency in the use of coal and of existing investment at the present time.

Many interesting examples of the methods and devices adopted to improve station and system economy and efficiency may be found throughout the country. In California, large electrical systems have been arranged to be tied together, electrically, for exchange of power. In Washington and Idaho, power systems under different managements have had similar arrangements. In the South, all important hydroelectric systems have been tied together for exchange of power. The advantage of such arrangements, as I have stated, is the better utilization of variable stream flow, improvement in load-factor, increased reliability of service; and the net result is to improve the efficiency of the system, not only financially, but in a purely technical sense. One most important advantage is the obvious reduction of the necessary investment in reserve machinery of every description.

In Montana, eight hydroelectric plants successively use the same stream flow, the total effective head amounting to 600 feet, and not only is the natural flow of the stream thus successively utilized, but all the storage water is effectively used by each plant in series. In this same system, the yearly load-factor is stated to reach 75 per cent and the mean monthly load-factor to reach 80 per cent.

The interconnection of hydroelectric plants brings about another extremely important saving, based upon the variation of rainfall in amount and time on the different watersheds which are thereby brought to serve a common system. It frequently happens that there will be plenty of precipitation on one watershed, while another watershed may suffer from long-continued drought. This condition varies not only in the same year but in different years. Interconnection serves to eliminate these variations by a process of averaging, and where the interconnected system covers a sufficiently wide area, a remarkable increase in total useful power is made available.

It has frequently happened that thousands of horse power have been wasted over the dams of one system, the watersheds of whose plants happened to have a wet year; and, at the same time, a nearby hydroelectric plant, supplied by another watershed, was without water power. The result has been that one system wasted power while the other was suffering from a power shortage which would frequently be made up by burning a large amount of high-grade coal in the operation of an auxiliary steam plant. This condition has to a large extent been remedied by the interconnections referred to

It has been estimated, and it seems a conservative estimate, that through the saving in reserve equipment, improvement in load-factor, and the diversity of different loads the useful output of groups of large systems may, through interconnection, be increased about 25 per cent.

Electric regeneration of power, that is the utilization of the weight of trains running on a down grade, due to the force of gravity, to generate electricity which is fed back into the electric system to help other trains up grade, is an illustration of the same important improvement in system efficiency.

I have thought it desirable to call your attention to the improvements obtained in system economy or efficiency because of the important savings in investment, in coal, in transportation, in labor, and in material which, in the aggregate, have already been realized. It illustrates the wonderful flexibility, value and economy of a general system transmitting energy by electricity, compared with any other possible method.

These advances have been more rapid during the last year, due to the imperative demands for economy, saving, and increased efficiency imposed by the war It is a great satisfaction that the foundation had all been well prepared during the times of peace

The development of our industry has been so rapid that the need of intelligent and constructive standardization was realized some years ago. The Standards Committee of the Institute, formed in 1898, has been of inestimable value to the profession and to the industry The standards adopted have been flexible enough to ensure progress and yet to discourage variations which were valueless The standards promulgated by our committee have so appealed to the profession and to the industry that they have been cheerfully followed, and I am convinced that, as a result, the cost of electrical apparatus to the consumer has been greatly reduced over a number of years, and the quality has not been sacrificed but has been improved I consider that the money value of the work so done could be conservatively placed at many millions of dollars.

Sixty-cycle systems have shown, during the past few years, a more rapid growth than have the 25-cycle, and it is now estimated that 60-cycle systems represent about 70 per cent of the total power supplied in the country. This is undoubtedly due to the lower cost of transformers, generators, induction motors, and similar apparatus. The relative growth of 60-cycle as compared with 25-cycle systems is reflected in steam-turbine installations. In 1910 about 60 per cent of the steam-turbine electric energy of the country was supplied from 60-cycle units; in 1917, this had risen to approximately 75 per cent.

This is an instance where standardization is desirable and economical. It will hasten the time, so often predicted, when a network of transmission lines, carrying electrical energy, will cover the country. These will be fed by super-power stations, suitably located with respect to cheap and reliable supplies of coal for fuel and water for condensing purposes, and into the same network will also be fed energy from the various hydroelectric installations.

Marked advances have been made during the past year in the application of electricity to the electric furnace. It is estimated that the number of electric furnaces in the United States has increased about forty per cent in the past year and that there are now in operation over five times the number that existed five years ago. The world's output of steel from electric furnaces has now grown to approximately four million tons per annum.

Experience has demonstrated that the electric furnace can utilize the cheapest and the most inferior raw material to produce steel of the most uniform and highest quality, with the greatest regularity. The cost of steel so produced, while reasonable, considering its quality, was higher, until recently, than that produced by the open-hearth method. It is now possible to produce electric steel at substantially the cost of that produced by the open-hearth method. This result has been brought about partly by the increased cost of the open-hearth method, due to a variety of well-known causes, but largely by a reduction in the cost of electric furnace operation. The marked change which has taken place in the reduction of the cost of operating electric furnaces is based upon greatly increasing the rate at which energy is delivered to the metal, both during the melting and the refining period. This has reduced the time required for an individual heat and also the kilowatt-hours required per ton of metal melted, with a net result of increasing the daily output of the furnace.

As a concrete example, I mention the history of a 5-ton furnace. It was originally supplied with 800 kv-a. at 80 volts. This was increased to 2000 kv-a. at 150 volts for the melting period and about 1400 kv-a. at 100 volts for the refining period. The time for the heat was reduced from six to three hours, the power consumption was reduced from 877 kw-hr. to 588 kw-hr. per ton, and the number of heats per 24 hours was increased from three to five, thus increasing the net output from 15 to 25 tons.

Electric resistance furnaces of large sizes, for special heat treatment requiring unusual exactness, are being extensively used, producing results greatly superior to oil- or gas-fired furnaces.

Electric welding, both by the arc and incandescent method, is being rapidly extended and is destined to greater development in shipbuilding and similar operations.

Electrical engineers have been devoting much time to the solution of many war problems. It is not desirable or possible to review such work at present, but when the veil is lifted we shall all be gratified with the result. We must content ourselves with the mere statement that this work has covered means for the detection of the pirate submarine; wireless signaling and telephoning for the army and navy, and aircraft devices; searchlights of novel design and great power; improved methods in manufacture of ammunition, ordnance, etc.; electrochemical work of every description; electric welding; X-ray sets of greater simplicity and accuracy; and many other lines too numerous to even mention.

The great industrial research laboratories, and the educational and governmental research departments have all co-operated enthusiastically and effectively, and the members of their staffs have labored day and night, without regard to pecuniary reward or public applause, sustained entirely by the high purpose of giving their best to the service of the country. I hope the time may come when the story may be told, so that the world may realize the debt which it owes to scientific men and engineers, without whose arduous, unselfish, and almost inspired work our cause, righteous as it is, would have no chance of a victorious conclusion.

In my address at the opening of the mid-winter convention of the Institute, in February, 1918, I called attention to the advantages which it seemed to me would follow a more general electrification of the steam railroads of the country. I merely repeat at the present time that electric locomotives have been so improved and simplified that they are competent to haul the heaviest train that can be held together with the present train construction; to operate at the highest speed permissible by the alignment of the road and independent of its grades; and that the electric locomotives can meet in the most efficient and adequate manner the transportation problems confronting the country, and offer better results than are now obtained or seem possible with steam locomotives.

There can be no question that railroad electrification is not only economical but imperatively needed to improve the present standards of steam operation. Our mountain districts are congested almost entirely by the limitations of the steam railroad systems, and the addition of more tracks, under such conditions, is not the best solution of the problem. The electrified divisions of the steam roads have been free from troubles during the past severe winter, and I repeat that the coal famine which the country suffered last winter could have been largely avoided if the steam railroads had been electrified. Moreover, it should not be forgotten that steam locomotives burn about 25 per cent of the entire coal mined in the United States, and that 12 per cent of the entire ton-mileage movement of freight and passengers carried over our railroad tracks is represented in cars and tenders required to haul coal to supply steam for the locomotives.

It is a truism, which has been frequently stated, that war requires the mobilization of the nation's industries and their devotion to essential work. This is especially true in this country, as it has been necessary, in addition, to create substantially new industries on an enormous scale, such as the production of ships, ordnance, ammunition, airplanes, chemicals, etc. To operate these industries, it has been necessary to mobilize to the fullest extent our available material and labor, but material and labor can only be converted into war work by the application of power. This power, in view of its great economy and flexibility, must be electrical.

While this country was fortunate in having available a magnificent system of power stations, so great was the magnitude of the demand for increased power, created by the war industries, that it is estimated that there will be a shortage of at least 500,000 kw. of electric power in the Eastern district.

It takes from one to two years to build and equip the large units which are essential for the production of such power. This illustrates the importance of all of the methods which I have mentioned to conserve, utilize, and increase the efficiency of existing equipment and investment, as such methods can produce results in a much shorter time.

It is, however, vitally important that the great electrical power-producing companies of this country should be helped in every way to meet the heavy demand which is placed upon them. It has been demonstrated that the quickest, most efficient, and altogether best way to meet the demand for power is through the expansion of such existing organizations and installations.

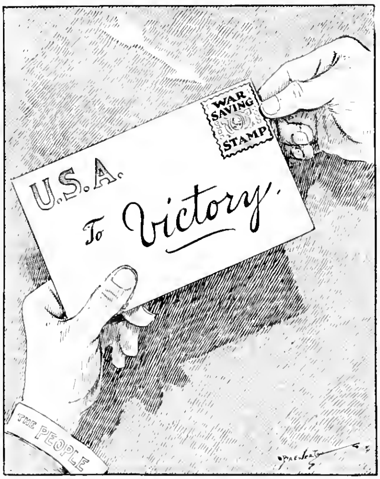
Fortunately, there is general appreciation of the fact, and comprehensive schemes are under consideration which will provide for the erection of large steam-electric power stations in the mining regions. Favorable locations exist which are within reach by transmission lines of electric power stations now serving large industrial areas. By interconnection, present investment and machinery will be better utilized and a large amount of additional electric power made available, without making any increased demand upon our congested railroad facilities.

It is evident, therefore, that we need to consider and put into effect every practical method for conserving our existing developments; and, also, we should take a courageous view of the future; we should provide for the future growth at least as liberally as has been the custom of the managers of the great public-service systems in the past. It has been their custom to build from two to three years in advance of existing requirements, in anticipation of the future. I have yet to learn of a single important instance where such foresight has not been amply justified.

I would say in conclusion that the saving in fuel, by such improvements as I have mentioned in various parts of my address, amounts to many millions of tons every year; the saving in material and investment represents millions of dollars, which manifestly represent service of the highest value to the industry and to the country. Such work is just as much the province of the electrical engineer as improvements in the design and efficiency of the electrical units, and requires the same scientific ability, vision, and industry.

While I admit to considerable prejudice in favor of things electrical, I think that in no other field of engineering has there been such a remarkable improvement and a condition which so nearly approaches 100 per cent, in the matter of efficiency, as has been shown in the field of electricity. This phenomenal record is not the result of accident. It has been due to the enthusiastic devotion of the scientist and engineer and executives to their work. They have not been satisfied with things as they are, or with mediocrity. They have wanted the best, and have not been contented with a 75 to 80 per cent efficiency when something better was obtainable. The causes of inefficiency have been scientifically attacked, the losses have been studied and their causes discovered and removed.

Concurrently with the improvements in the efficiency of conversion, the engineer has studied ways and means to reduce the amount of material and the amount of labor required to produce a given effect, and has been equally successful in increasing the effective use of material and labor; and, as a result, until interrupted by the war, the cost of electrical machinery and devices of every description has shown a progressive reduction, not only without sacrifice of quality but with great improvement in quality. This truly marvelous work, we can safely affirm, is the foundation of the phenomenal growth, prosperity, and present commanding position of the electrical industry, which is a monument to the broad vision, intellectual honesty, faithful work, and the correct economic viewpoint of the electrical engineer and his co-workers.



Fundamentals of Illumination Design

PART IV. APPENDIX OF ILLUSTRATIVE PROBLEMS

By Ward Harrison

National Lamp Works, General Electric Company

This installment, which concludes the series, shows how the principles and data of the previous installments are applied to the solution of actual lighting installations. Four problems are worked out, covering the lighting requirements of four different kinds of establishments. A careful study of the series should enable the engineer to design a lighting system for almost any service that will provide satisfactory illumination and accord with the best practice.—Editor.

PROBLEM I—OFFICE LIGHTING

It is desired to install a modern lighting system in a large general office of which the floor plan is shown in Fig. 1. It will be noted that a row of columns 10½ feet apart extends lengthwise down the center of the room. The problem is to be solved on the basis of the following data:

Dimensions:
- Width 29 feet
- Length 105 feet
- Ceiling height 15 feet

Color of ceiling—very light cream
Color of walls—greenish grey, medium

satisfactory and were chosen for this particular office.

Table I[1] gives 4–8 foot-candles as satisfactory intensities for office lighting. In view of the fact that in this office lighting is required for a considerable portion of the day, an intensity of 7 foot-candles will be used as the basis for solution. This intensity, however, must be increased somewhat to offset the decrease due to lamp depreciation and dust collection on the units. A depreciation factor of 1.20 can be used satisfactorily in this case; the installation must provide, therefore, an initial intensity of 8.4 foot-candles. The coefficient of utilization for

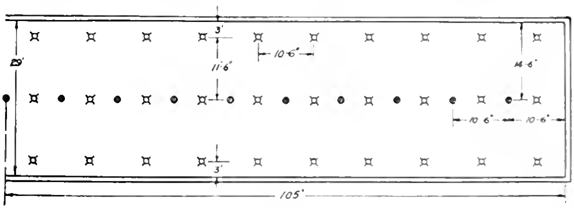


Fig. 1. Floor Plan of a Large General Office (Problem I)

It will be noted that the room is long with respect to its height and a large number of the persons occupying the room will, therefore, be forced to have lighting units within the visual field a greater part of the time. For this reason the lamp filaments must be completely screened from view. This conclusion together with the light cream ceiling and greenish-grey walls at once suggests the use of indirect or semi-indirect units. Totally indirect units possess the advantage that their use in this office would insure an almost complete avoidance of glare. On the other hand, *dense* semi-indirect units are equally

dense opal semi-indirect units used in the office in question is found from Table II[2] as follows:

$$\text{Ratio, } \frac{\text{Room width}}{\text{Ceiling height}} = \frac{29}{15} = 1.93 \text{ (Use 2)}$$

Coefficient of Utilization = 0.31

$$\text{Ratio, } \frac{\text{Room length}}{\text{Ceiling height}} = \frac{105}{15} = 7 \text{ (Use 5)}$$

Coefficient of utilization = 0.42

Final coefficient = 0.31 + ⅓ (0.42 − 0.31) = 0.34 + [illegible]

[1] General Electric Review, June 1918, page 423; [2] June 1918, page 424; [3] June 1918, page 426; [4] June 1918, page 428.

EXAMPLE OF A WELL-LIGHTED STORE
Two Views in the Establishment of Livingston Bros., San Francisco

The total number of lumens which must be supplied is now found to be

$$\frac{8.4\times29\times105}{0.34}=75,200$$

By use of the spacing ratio given for semi-indirect units in Table III,[3] the maximum allowable spacing is found to be 18¾ feet. As has been pointed out, it is always advisable in placing outlets to consider the location of columns with respect to the possible future subdivision of the area. In this office it was thought very desirable to have the installation symmetrical with the columns, at least in the direction lengthwise of the room. Hence, not less than two rows of 10 units each, spaced 10½ feet lengthwise of the room, are required. Since the units must furnish 75,200 lumens, each of the 20 units must supply 3,760 lumens, and reference to Table IV[4] shows that the 300-watt Mazda C lamp is required. An alternate spacing plan which suggests itself is to use three rows of units spaced 12½ feet apart lengthwise and 11 to 12 feet crosswise of the office. This calls for 30 units, and if 200-watt lamps are used the power requirement will be the same as with the previous arrangement. Notwithstanding the fact that the installation of the 30 units necessitated a greater cost of installation, this arrangement was adopted, first, because it brings the outlets more nearly in squares, and second, because of the fact that the brightness of the semi-indirect bowl selected—and hence the liability of eyestrain—is considerably less with the 200-watt lamps. The outlets were located as shown in Fig. 1.

This example illustrates the points previously brought out, that permissible spacing distances as calculated from Table III[3] should be regarded as maximum spacing distances and that closer spacings do not detract from the uniformity of illumination and can frequently be used to advantage.

Fig. 2. Solution to Office Lighting Problem (Problem 1)

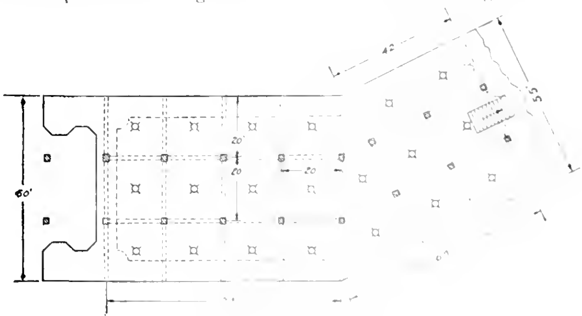


Fig. 3. Floor Plan of a Large Clothing Store (Problem 2)

[illegible]

[1] General Electric Review, June 1918, p. 42[illegible]

pension distance equal to from one fourth to one third the spacing distance is satisfactory.

Fig. 2 shows the lighting system described in operation.

PROBLEM 2—STORE LIGHTING

It is desired to light the main floor of a large clothing store located in the principal business section of a large city. The floor plan of the store is shown in Fig. 3. A mezzanine floor extends around the entire main floor and for this reason and for the reason that high cases line the walls, little of the light striking the walls will assist in illuminating the store proper. Although the walls are finished in a light color they must, therefore, be considered "dark" for purposes of calculation. The basic data are as follows:

Fig. 4. A Well-lighted Clothing Store (Problem 2)

Dimensions:
- Front portion of store
  - Width 60 feet
  - Length 78 feet
- Rear portion of store
  - Width 55 feet
  - Average length 55 feet

Ceiling height 16 feet
Color of ceiling—light cream
Color of walls—"dark"

For this installation the store management has been favorably impressed with the appearance of opal enclosing units of ornamental design, and such units are accordingly chosen, bearing in mind the importance of securing an opal which while "light" as regards absorption, will diffuse the light thoroughly.

By reference to Table I[1] it is seen that the intensity suitable for a store on a bright street ranges between 7 and 10 foot-candles. A value of 8 will be taken as a desirable working value. This value multiplied by a depreciation factor of 1.20 gives 9.6 foot-candles as a desirable initial value. The coefficient of utilization is found in the usual way to be approximately 0.38. The total area of the store is 7,705 square feet; hence the total lumens which must be generated initially are $\frac{9.6 \times 7,705}{0.38} = 194,600$. It will be noted from the floor plan shown that the ceiling is divided by beams into 21 bays. A desirable location of units would be a single unit at the center of each of these bays with perhaps no unit in the one small triangular bay formed by the angle of the building. The bays average approximately 20 feet square, hence the spacing of the units would be about 20 feet. It is seen from Table III[3] that a 20-foot spacing of totally enclosing units calls for a mounting height of 12 feet for uniform illumination. The distance between the ceiling and the working plane is in this store 13 feet and enclosing units can therefore be used.

Since 20 units are to supply 194,600 lumens, each unit must generate 9,730 lumens—more than the 500-watt lamp will supply and less than the 750-watt lamp will furnish. From the standpoint of good vision it is unquestionably true that 500-watt lamps would provide sufficient illumination (about 6.6 foot-candles) and would ordinarily be used, but in this case the management attached very decided importance to the advertising value of a high intensity and installed 750-watt Mazda C lamps.

The installation discussed is shown in Fig. 4. It will be noted that the units were, from considerations of appearance, dropped a somewhat greater distance from the ceiling than the calculations called for. Although this

[1] General Electric Review, June 1918, page 423; [2] June 1918, page 424; [3] June 1918, page 426; [4] June 1918' page 428.

mounting involved a sacrifice in uniformity, the fact that a high intensity was used gave assurance that at all points the illumination would be adequate. It will be noted from the photograph that the units are of very large size and hence their brightness is of a sufficiently low order so that it does not interfere with good vision.

PROBLEM 3—INDUSTRIAL LIGHTING

It is desired to light a furniture factory. The greater part of the work can be classed as fine woodwork. Fig. 5 shows the floor plan. It will be noted that work benches line three sides of the room.

For this installation the dome-shaped porcelain-enameled steel reflector is selected, for it is efficient, durable, and provides a desirable distribution of light. The diffusion of light which it affords is entirely satisfactory for a woodworking plant. The following data are to be used as a working basis:

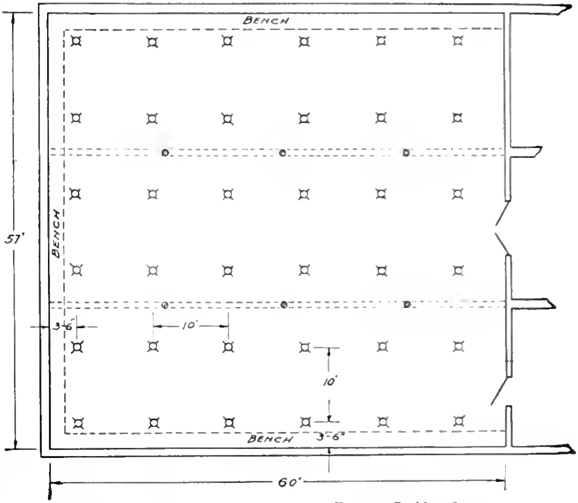


Fig. 5. Floor Plan of a Furniture Factory (Problem 3)

Dimensions:

Width	57 feet
Length	60 feet
Ceiling height	12 feet

Color of ceiling—white
Color of walls—white

Table I[1] gives 4–8 foot-candles as satisfactory intensities for fine work. In contrast with the metal trades, the surfaces worked upon have for the most part a fairly good reflection factor, and therefore should appear sufficiently light under an intensity of 5 foot-candles. Particles of sawdust are carried about by the air in woodworking shops and although light in color collect rather heavily on the lighting units. For this reason the desirable intensity is multiplied by a depreciation factor of 1.30 to insure that the average intensity will not fall below the desired value. This gives an initial working intensity of 6.5 foot-candles. The coefficient of utilization for dome-shaped porcelain-enameled steel reflectors for this particular room is found from Table II[2] to be 0.69. The total generated lumens necessary to produce an initial intensity of 6.5 foot-candles on the working plane are

$$\frac{6.5 \times 60 \times 57}{0.69} = 32{,}200 \text{ lumens.}$$

Fig. 6. Lighting Installation over Benches (Problem 3)

[1] GENERAL ELECTRIC REVIEW, June 1918, page 423; [2] June 1918, page 424, [3] June 1918, page 426, [4] June 1918, page 428.

Table III[3] gives $1\frac{2}{3}$ as the maximum spacing ratio for dome-shaped steel reflectors. In this problem the maximum mounting height above the working plane is about 8 feet. The maximum allowable spacing distance is, therefore, 13.3 feet. The dimensions of the room allow

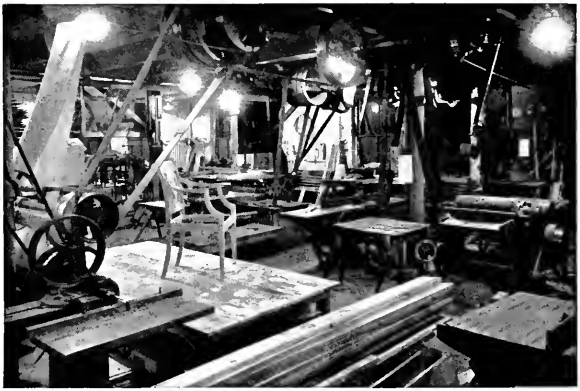


Fig. 7 Illumination of Woodworking Plant (Problem 3)

a symmetrical arrangement of 5 rows of 5 units each spaced on approximately 12-foot centers. However, since it is desirable to provide a system more nearly symmetrical with respect to the bays, and since a row of units should be provided over each of the benches which line three sides of the room, it will be better practice to install 6 rows of 6 units each, locating one row $3\frac{1}{2}$ feet from each of the three walls along which the benches are placed, as shown in Fig. 5, and spacing the remaining units at 10-foot intervals in rows 10 feet apart. With this arrangement 36 units are required. If 36 units are to generate 32,200 lumens, each unit must generate approximately 895 lumens. Reference to Table IV[4] shows that the 75-watt Mazda C lamp will supply 865 lumens and should insure adequate illumination. Bowl-frosted lamps are necessary to minimize glare.

The photographs reproduced in Figs. 6 and 7 show the installation described in this problem.

PROBLEM 4—INDUSTRIAL LIGHTING

It is desired to light an industrial plant manufacturing tools and other similar metal parts. In order that glare shall be avoided, and that shadows shall not be objectionable, the metal-cap diffusing unit shown in Fig. 10, July G. E. Review, will be used. Since this unit is only available for use with 75, 100, 150, 200, and 300-watt Mazda C lamps, the choice of lamp size is limited to a certain extent.

The following data are given as a working basis:

Dimensions:

Length	100 feet
Width	30 feet
Ceiling height	15 feet

Color of ceiling—light
Color of walls—medium

Table I[1] gives 4–8 foot-candles as satisfactory intensities for metal-working plants. In this case an intensity of at least 6 foot-candles is desirable. This value is multiplied by a depreciation factor of 1.25 to offset the decrease in illumination certain to result from lamp depreciation and dust collection, and the initial desirable intensity becomes 7.5 foot-candles.

This metal-cap diffusing unit is a special rather than a general type, and hence it is not listed in Table II[2]. However, it gives about the same proportion of the total light—60 per cent—in the lower hemisphere as does the semi-enclosing unit, and as may be seen from Fig. 8 its distribution curve is, in general, similar to that of the semi-enclosing unit below the horizontal, although the latter

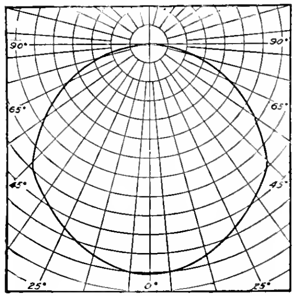


Fig. 8. Distribution Curve of Metal-cap Diffusing Unit (Problem 4)
Lumens Output from Bare 200-watt Lamp—2920
Lumens Output from 200-watt Unit 1750

[1] General Electric Review, June 1918, page 423; [2] June 1918, page 424; [3] June 1918, page 426; [4] June 1918, page 428.

unit gives higher candle-power values near the horizontal. Since with dark walls and ceiling light given off near the horizontal and above has, in industrial plants, little effect on the illumination of the working plane, the coefficient of utilization applying to semi-enclosing units for rooms with dark ceiling and walls can always be used safely for the metal-cap diffusing unit. The spacing ratios applying to the semi-enclosing unit can also be used. From the data given in Table II[2], the coefficient of utilization to be used is found in the usual way to be 0.38. The total generated lumens required are then

$$\frac{7.5 \times 30 \times 100}{0.38} = 59{,}200 \text{ lumens.}$$

The maximum allowable spacing distance is found from Table III[3] to be $1\frac{1}{2}$ times the hanging height. The maximum height at which units can be mounted above the working plane is about 11 feet. Hence, the maximum allowable spacing distance is 16.5 feet.

The dimensions of the room permit the use of two rows of 6 units each or a total of 12 units, but 12 300-watt Mazda C lamps—the largest size which can be used with available metal-cap diffusing units—will not give a sufficiently high intensity of illumination. Moreover, the

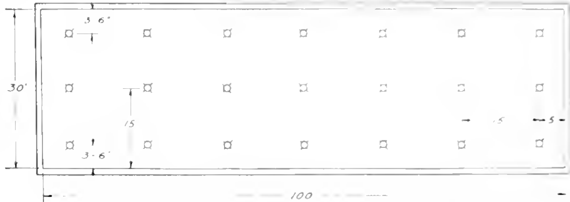


Fig. 9. Floor Plan of Metal-working Plant (Problem 4)

location of work benches along the side walls makes desirable the location of a row of units over each of the benches at a distance of $3\frac{1}{2}$ feet from the walls. If two rows of units were so located, the distance between the rows would exceed the allowable spacing distance; hence it is desirable to install three rows of units, one over the two rows of work benches at a distance of $3\frac{1}{2}$ feet from the side walls, and one in the center of the room. Such an arrangement calls for a distance of $11\frac{1}{2}$ feet between rows. Since in this problem the distance between units in a row lengthwise of the room is limited only by the allowable spacing distance, a spacing of approximately 15 feet will provide uniform illumination and will provide an arrangement of units reasonably near square. Such spacing will require 7 units per row or a total of 21 units in all, as shown in Fig. 9. To provide 59,200 lumens, each unit must provide 2,820 lumens. Reference to Table IV[4] shows that the 200-watt Mazda C lamp supplies 2,920 lumens, and will therefore provide adequate light for the problem at hand. The installation is shown in Fig. 10.

Fig. 10. Installation in Metal-working Plant (Problem 4)

[1] General Electric Review, June 1918, page 423. [2] June 1918, page 424. [3] June 1918, page 426. [4] June 1918, page 428.

Methods for More Efficiently Utilizing Our Fuel Resources

PART XX. IS OUR FUEL SUPPLY NEARING EXHAUSTION*

By R. H. Fernald

Professor of Mechanical Engineering, University of Pennsylvania

We recommend that all read this article for everyone is responsible to some degree for the depletion of our fuel resources and should inform himself of the initial amount of our resources, the increase in the rate of their consumption, and the amount of the remaining reserves. The presentation of statistics is mainly limited to the tables and charts, the reading matter dealing principally with the observation of facts and conclusions to be drawn from them. The fuels considered are the various coals, peat, petroleum, gasolene, natural gas, and wood. In one section of the article, which treats of the 1917 fuel situation, is the best analysis we have seen of the conditions which led to the coal shortage of last winter.—Editor.

The Vital Importance of Fuel

"Food will win the war; don't waste it." This effective slogan has convinced us of the very essential part which conservation and proper distribution of food are to play in the ultimate winning of the war. Few of us, however, appreciate how vitally essential, if not paramount, is fuel in the great world struggle. Our slogan might well be: "Fuel and food will win the war; don't waste them."

Some months ago the Honorable Franklin K. Lane, Secretary of the Interior, was reported as saying, "Not only food, but fuel is a vital need of this country and of our Allies—coal to run the ships and railroads, to feed the iron furnaces and furnish steam for all the manufacturing plants, coal in greater quantities than have ever been mined in the United States or in any part of the world; and this is being met in truly American fashion by the operators and owners of the mines and by the diggers of the coal."

As pointed out by Van Hise† in 1910: "Coal is by far the most important of all the mineral products. Next to coal in importance is iron. These two are of much greater consequence than all of the other mineral products put together. The existence of extensive coal and iron fields has profoundly influenced modern civilization. The greatest commercial nations are America, England, and Germany, and each has extensive coal and iron deposits. Little Belgium, because of its important coal and iron deposits, is a hive of industry, occupying a position as a manufacturing nation far beyond what one would expect from its limited area and population."

That fuel is the backbone of the present titanic struggle for world supremacy was completely driven home by the collapse in Italy in the fall of 1917. "For the want of coal her industries stopped; for the want of shells her guns were spiked; for the want of guns her army was powerless; for the want of an army her country was conquered by the Hun—and all for the want of some tons of coal."

The World's Coal Supply

If it be true that the domination of the world will rest with those nations that own or control the two most important natural resources—coal and iron—a somewhat startling sidelight is thrown on our possible relation to the great problems of the present century by Campbell's‡ figures on the coal reserves of the world. These figures are given in Table I.

TABLE I

COAL RESERVES OF THE WORLD

Countries	Short Tons
Americas	5,627,823,500,000
Asia	1,410,487,600,000
Europe	864,412,600,000
Oceania	187,842,900,000
Africa	63,755,900,000
	8,154,322,500,000

The portion falling to the United States alone is 4,205,154,000,000 tons, or over half of all the coal in the world.

The coal reserves by countries are as shown in Table II and Fig. 1.

Amount of Coal Available in the United States

Of the tremendous stores of coal in the United States, a considerable portion lies below a practical mining depth. Although in some instances in European countries coal has been mined at a depth of 6000 feet, it is

* Read before the Engineers' Club of Philadelphia, February 19, 1918.
† "The Conservation of Natural Resources in the United States," Charles R. Van Hise.
‡ United States Geological Survey Professional Paper 100-A, by M. R. Campbell.

TABLE II

COAL RESERVES OF THE VARIOUS COUNTRIES

Countries	Short Tons
United States, including Alaska	4,231,352,000,000
Canada	1,360,535,000,000
China	1,097,436,000,000
Germany	466,665,000,000
Great Britain and Ireland	208,922,000,000
Siberia	191,667,000,000
Australia	182,510,000,000
India	87,083,000,000
Russia in Europe	66,255,000,000
Union of South Africa	61,949,000,000
Austria	59,387,000,000
Colombia	29,762,000,000
Indo-China	22,048,000,000
France	19,382,000,000
Other countries	69,369,500,000
	8,154,322,500,000

reports on the subject reveals the fact that the two greatest continuous coal areas lie in Montana, Wyoming, and the Dakotas, and represent nearly three and one-half times the total coal reserves of the entire Appalachian region. A serious situation confronts us, however, when we realize that our really high-grade coals—the semi-bituminous and anthracite of the eastern provinces amount to less than one seventh (or about 15 per cent) of the available coal reserves of the country.

Approximately an additional 15 per cent may be classed as coal of medium grade, but the bulk of our coal—70 per cent of the entire supply—consists of low-grade bituminous coals and lignites.

It is perhaps well to correct a rather general impression that anthracite is the highest grade fuel. As a matter of fact, our semi-bituminous coals rank first, as shown by Table III of comparative heating values per pound of combustible material.

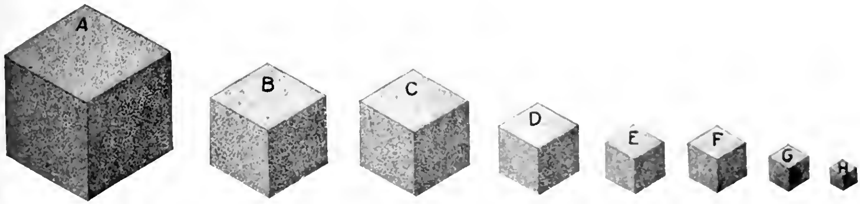


Fig. 1. Cubes Whose Size Indicate the Coal Reserves of the World by Countries
The amounts are given in Table II

A United States
B Canada
C China
D Germany
E Great Britain
F Siberia
G Russia
H France

hardly probable that for many years commercial conditions in this country will warrant the removal of coal at a greater depth than 3000 feet below the surface. Fortunately, nearly nine-tenths of the total estimated original coal reserves, or about 3,550,000,000,000 tons, lie at a depth not exceeding this 3000-foot limit.

Although we are becoming accustomed to talking in billions, it is hardly possible to grasp the meaning of thirty-five hundred and fifty billion tons of coal. Perhaps some conception of this amount may be had from the statement that if all the unmined coal within 3000 feet of the surface could be placed in one great cubical pile as solid as it now lies in the ground the pile would be eight miles long, eight miles wide, and eight miles high.

In this part of the country, we are inclined to think that the greatest coal deposits of the country are in the East and largely in Pennsylvania. An examination of the government

TABLE III

COMPARATIVE HEATING VALUES OF COAL

	B.t.u. per Lb. Ash Free
Semi-bituminous	15,420
Anthracite and semi-anthracite	14,660
Bituminous	13,970
Sub-bituminous and lignite	8,560

The exhaustion of these semi-bituminous coals would be a far greater calamity than the exhaustion of the anthracite supply, as they are much better adapted for general commercial purposes and are more efficient than anthracite, the latter being used but little outside of the domestic field.

World's Production of Coal

Naturally figures on the production of coal in Europe are not available for the past two or three years, but the relative production of coal by the different countries of the world in normal times is shown by the values given in Table IV and Fig. 2.

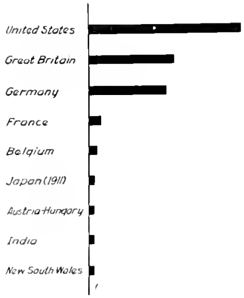


Fig. 2. The World's Production of Coal in 1912
The amounts are given in Table IV

TABLE IV

WORLD'S PRODUCTION OF COAL IN 1912

Countries	Short Tons
United States	534,500,000
Great Britain	306,000,000
Germany	282,400,000
France	45,400,000
Belgium	25,300,000
Japan (1911)	19,400,000
Austria-Hungary	17,400,000
India	15,700,000
New South Wales	11,100,000

Of the world's production for the year 1912, 1,364,000,000 tons (82 per cent) were produced by the United States, Great Britain, and Germany, the United States producing 39 per cent of the total, or nearly as much as Great Britain and Germany together.

TABLE V

COAL PRODUCTION OF THE THREE PRINCIPAL COAL MINING COUNTRIES

	SHORT TONS		
	1870	1890	1912
Germany	37,500,000	98,400,000	282,400,000
Great Britain	123,700,000	203,400,000	306,000,000
United States	33,000,000	157,800,000	534,500,000

The extent of our industrial development may be better appreciated when it is realized that all but about 4 per cent of our tremendous coal production is used in this country.

The rate of increase in coal production by the three principal coal mining countries is shown in Table V and Fig. 3.

Coal-producing States

Although it has been pointed out that our most extensive fuel areas are in the western part of the United States, industrial pursuits, the availability of oil, the convenience of natural gas, and other underlying causes have

Fig. 3. The Rate of Increase of Coal Production
The amounts are given in Table V

TABLE VI

PRODUCTION AND USE OF COAL BY STATES IN 1915

Countries	Produced (Short Tons)	Used (Short Tons)
Anthracite		
Pennsylvania	89,000,000	23,300,000
New York	....	20,800,000
New England	....	13,800,000
New Jersey	....	8,400,000
Illinois	....	3,300,000
Wisconsin	....	1,700,000
Minnesota	....	1,700,000
Maryland and District of Columbia	....	1,500,000
Remaining 30 states	....	4,400,000
Bituminous		
Pennsylvania	158,000,000	65,500,000
West Virginia	77,200,000	6,200,000
Illinois	58,800,000	40,000,000
Ohio	22,400,000	22,400,000
Kentucky	21,400,000	5,200,000
Indiana	17,000,000	16,100,000
Alabama	14,900,000	7,500,000
Colorado	8,600,000	5,100,000
Virginia	8,100,000	4,300,000
Iowa	7,600,000	6,900,000
Kansas	6,800,000	3,200,000
Wyoming	6,500,000	600,000
Tennessee	5,700,000	3,600,000
New England	....	20,500,000
Michigan	1,200,000	10,300,000
Missouri	3,800,000	7,700,000
Wisconsin	....	7,700,000
All other states	24,600,000	57,100,000

resulted in extensive coal production east of the Mississippi River and in comparatively little production throughout two thirds of the total area of the United States, as shown by Table VI of production and use of coal by the different states.

Of the individual states, with the exception of West Virginia, those producing coal are the largest users, 33 per cent of the 1915 output of bituminous coal being used within the states producing it.

Uses of Coal in the United States

In the main, anthracite is used for domestic purposes and bituminous for industrial purposes.

The largest users of coal are the industrial steam trade, requiring over 30 per cent of the mine output; the railroads, requiring about 24 per cent; domestic and small steam trade—heating dwellings, apartment houses, hotels, office buildings, and heating and steam raising in small power plants—requiring 23 per cent. It is thus seen that even in normal times (1915) these three demands call for 412,000,000 tons, or 77 per cent of all the coal mined in the United States.

It is interesting to note from Table VII and Fig. 4, that the railroads used 122,000,000 tons of bituminous coal and 6,200,000 tons of anthracite, and that the great industrial state of Pennsylvania used 65,511,000 tons of bituminous coal and 23,293,000 tons of anthracite. In other words, the railroads of the country used nearly twice as much bituminous coal as the entire state of Pennsylvania, but only a little over one third as much anthracite as Pennsylvania. The total coal consumption, anthracite and bituminous combined, of the railroads is equal to nearly one and one half times the total coal consumption of the state.

Exports and Imports

Contrary to popular belief, the amount of coal exported is very small. In 1915, our coal

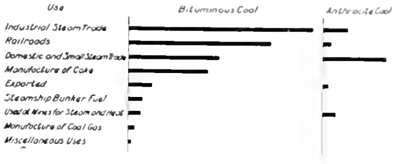


Fig. 4. The Uses of Coal in the United States in 1915
The amounts are given in Table VII

exports amounted to only 22,700,000 short tons, which was 13 per cent more than for 1914, but 8 per cent less than for 1913. During these years Canada took from one half to three fourths of the exported coal. The total exports amount to only about 4 per cent of the total coal production.

TABLE VII

USES OF COAL IN THE UNITED STATES IN 1915

Use	Bituminous		Anthracite	
	Short Tons	Per Cent	Short Tons	Per Cent
Industrial steam trade	143,800,000	33.0	18,800,000	21.1
Railroads	122,000,000	28.0	6,200,000	7.0
Domestic and small steam trade	71,300,000	16.0	50,000,000	56.2
Manufacture of coke	61,800,000	14.0		
Exported	18,800,000	4.2	4,000,000	4.5
Steamship bunker fuel	10,700,000	2.4		
Used at mines for steam and heat	9,800,000	2.2	10,000,000	11.2
Manufacture of coal gas	4,600,000	1.0		
Miscellaneous uses	700,000	0.2		

As pointed out by the United States Geological Survey "The noteworthy features of the export trade in 1915 were the increasing demand throughout the year from Europe and South America, and in the latter part of the year the scarcity of vessels in which to ship coal to these countries. If the supply of vessels had been adequate, the exports undoubtedly would have been greater."

Our importations of coal are small, amounting to about one third of [illegible] per cent of the [illegible] coal production. Practically all [illegible] are to the New England states, the [illegible] western states and California. [illegible] the accessibility of Canadian coal and local transportation facilities.

How Long Will This Wonderful Coal Supply Last?

The use of coal as the chief source of fuel is comparatively new. With the possible

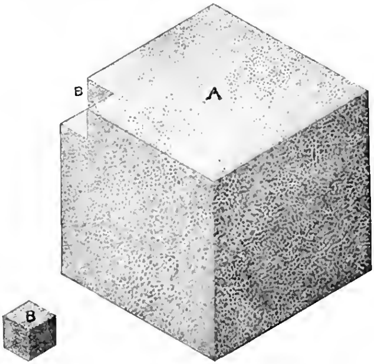


Fig. 5. The Total Available Coal in the United States and the Exhaustion to the Close of 1917

A—Total coal—3,550,000,000,000.
B—Total exhaustion—18,000,000,000.

exception of a few European countries, the forests were depended upon for fuel until within fifty or seventy-five years. Although the draft upon our coal supply has just begun, it is time for us to realize that on account of the abundant supply and wide distribution of our fuel resources, on account of our relative freedom from large areas of congested population, and on account of our careless indifference to efficient utilization, we have neglected far too long the serious consideration of problems upon which hinge many of the possible activities of future generations.

The unrestricted use of our better grade fuels and the ruthless waste and neglect of fuels that should be of real commercial value are phases of our national extravagance that are little short of appalling.

In attempting to estimate the probable life of our coal supply it is necessary to determine (*a*) the draft we have already made upon the original supply and (*b*) the rate at which this draft is being made.

In a little over one hundred years, we have taken from the mines to the close of 1917 something over 12,000,000,000 tons. If we assume the usual loss of one half ton for every ton mined, the total exhaustion has amounted to 18,000,000,000 tons, which is one half of one per cent of the original available supply lying at depths not exceeding 3000 feet. Packed as densely as it lies in the ground, and remembering that the original supply in the storehouse would make a pile whose length, breadth, and height would be eight miles, the portion drawn away or exhausted to date would be represented by a slice eight miles long and eight miles wide and only 0.04 mile (210 feet) high.

If the consumption for the past one hundred years could be taken as a basis, we might reasonably expect our coal supply to last some 20,000 years, but we must remember that we only began to use coal a little over one hundred years ago and it takes the total production of the first sixty-eight years (from 1807 to 1875) to equal the production of the single year 1917. If for all future time we were to mine coal at an annual rate just equal to that of 1917 (about 640,000,000 tons), with an allowance for unpreventable waste, then the coal supply should last 4000 years, but it is well known that in 1917 the demand was greater than the supply, and there is ample evidence to show that for years to come the demand will be an ever-increasing one. An examination of Table VIII and Fig. 6, our average annual coal production by decades since 1807, shows with what rapidity the rate of consumption is growing.

TABLE VIII

AVERAGE ANNUAL PRODUCTION OF COAL IN THE UNITED STATES BY DECADES FROM 1807 TO THE CLOSE OF 1917 (111 YEARS)

	Short Tons
1807–1817	1,000
1818–1827	65,000
1828–1837	608,000
1838–1847	3,100,000
1848–1857	10,000,000
1858–1867	20,700,000
1868–1877	47,300,000
1878–1887	97,800,000
1888–1897	173,000,000
1898–1907	333,000,000
1908–1917	525,000,000

Campbell* points out that if the acceleration shown by the figures for coal consumption by decades be continued until the coal is completely exhausted, the supply will probably not last one hundred years. He says, however, "The true life of our coal fields probably lies between these two extremes, and the probability is that it will be nearer 100 than 4000 years."

* "The Coal Fields of the United States," United States Geological Survey Professional Paper 100-A.

Of equal significance is the increase in our per capita consumption of coal, shown by Table IX and Fig. 7.

TABLE IX

PER CAPITA COAL CONSUMPTION IN THE UNITED STATES

Year	Short Tons	Percentage Increase
1870	0.96	
1880	1.4	45.8
1890	2.3	64.1
1900	3.2	39.1
1915	5.5	71.9

Far more serious than the general drain upon all of the fuel resources of the country is the extravagant use of our highest grade material. The very best coal in the storehouse—the semi-bituminous of the eastern Appalachian field—amounts to a very small percentage of the coal resources, and it is this high-grade steaming coal that we are using with extravagant recklessness and without thought of the future. As E. W. Parker recently said in an address at The Franklin Institute, "We are rapidly consuming the cream and leaving the skimmed milk."

Before discussing the apparent coal shortage and serious fuel inconveniences of 1917, let us see what other natural fuel resources we possess.

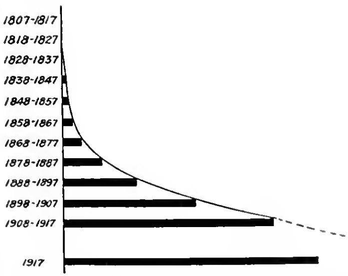


Fig. 6. The Average Annual Production of Coal in the United States by Decades from 1807 to the Close of 1917 (111 years). The amounts are given in Table VIII

Peat

In the swamps and bogs of the northeastern states, of the states near the Great Lakes, and along the south Atlantic coast are large deposits of partially decomposed vegetable matter or peat. Commercially dry peat has a fuel value per pound equal to only about one half the value of the higher grade coals, but nearly, if not quite, equal to the lower grade coals, or lignites. From the standpoint of by-products, peat, perhaps, offers a more enticing field than the majority of coals.

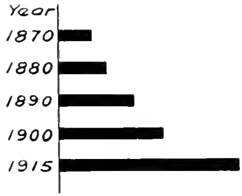


Fig. 7. Per Capita Coal Consumption in the United States The amounts are given in Table IX

Peat has been used for centuries in Europe as a domestic fuel, but not until within the past decade has it reached any importance as a fuel for power plants in competition with coal and lignite. Although considerable peat is now mined in the British Isles, the greatest developments in the use of this fuel have been in Germany, Norway, Sweden, and Russia, the amount mined in Russia alone amounting to several million tons annually.

The estimated deposits of the United States amount to about 13,000,000,000 tons of air-dried peat. Although this amount seems small when compared with our coal and lignite deposits amounting to only one half of one per cent of these deposits—yet the available amount is equal to the total tonnage of coal mined in this country in the past one hundred years. It should be noted that peat is found largely in states possessing no coal, which may prove an important factor in the ultimate solution of power distribution. Inasmuch as peat can be of no immediate service in our present fuel troubles, the discussion of this resource will be dismissed with the statement that within a comparatively few years peat will be highly valued in this country, not only as a fuel, but for other commercial purposes for which it seems admirably adapted and for which it is now being used in several European countries.

Petroleum and Natural Gas

We are all so familiar with the demands for and the use of coal and see such extensive shipments moving in all directions as we travel that few of us appreciate the enormous value of two other fuel resources with which this country has been richly endowed—petroleum and natural gas.

An appreciation of the value of these products may be had from the following Table X of the value of the mineral products of the United States in 1913.

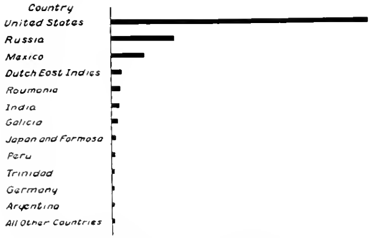


Fig. 8. The World's Production of Petroleum in 1916
The amounts are given in Table XI

TABLE X

VALUE OF THE MINERAL PRODUCTS IN THE UNITED STATES IN 1913

Coal	$760,000,000
Iron	458,000,000
Petroleum	237,000,000
Copper	190,000,000
Clay products	181,000,000
Cement	93,000,000
Gold	89,000,000
Natural gas	88,000,000
Stone	84,000,000
Silver	40,000,000
Lead	38,000,000
Zinc	38,000,000
All others	149,000,000

Third in the list stands petroleum, being surpassed only by coal and iron; and the annual value of natural gas is practically equal to that of gold.

These three products—coal, petroleum, and natural gas—make up nearly one half the total value of all our mineral products.

Of course, petroleum has other important uses outside of its demand in the field of fuels.

The position of the United States in relation to the world's production of petroleum, Table XI and Fig. 8, is even more marked than its relation to the world's production of coal, nearly two thirds of the total annual production of petroleum coming from this country.

A comparison of the production and value of the petroleum marketed in the United States in 1915 and 1916 is shown in Table XII.

* United States Geological Survey.

From the beginning of the petroleum industry in the United States to the close of 1917 this country produced approximately 4,250,000,000 barrels, or about 60 per cent of the entire production of the world for this period.

Future Supply of Petroleum

According to most careful estimates of the United States Geological Survey, the probable total original petroleum resources of the country amounted to over 11,000,000,000 barrels, of which the exhaustion to the close of 1915 amounted to over 3,600,000,000 barrels, leaving for possible future production about 68 per cent of the original supply, or some 7,600,000,000 barrels.

If we assume a lake 100 feet deep and one mile wide, the length of the lake corresponding to the estimated total original petroleum resources would be over 22 miles. The exhaustion means that we have cut off more than 7 miles from the length of the lake and have left the equivalent of a lake 15 miles long, 1 mile wide, and 100 feet deep.

The petroleum fields of the United States are known as the Appalachian, the Lima-Indiana, the Illinois, the Kansas-Oklahoma, the North Texas, the Northwest Louisiana, the Gulf Coast, the Colorado, the Wyoming-Montana, and the California fields.

Although the draft upon some fields has been but a small percentage of the available resources, notably only 2 per cent exhaustion for the Wyoming-Montana field and 8 per cent for the North Texas field, and although the exhaustion for all fields combined amounts to 32 per cent, the proportion left in some fields is very small, the exhaustion of the Appalachian field having been 70 per cent and of the Lima-Indiana field, 93 per cent.

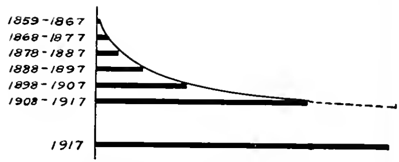


Fig. 9. The Average Annual Production of Crude Petroleum in United States by Decades. The amounts are given in Table XIII

As in the case of the coal resources, the alarming point is the rapidly increasing rate of exhaustion, as shown by Table XIII and Fig. 9.

TABLE XIII

AVERAGE ANNUAL PRODUCTION OF CRUDE PETROLEUM IN THE UNITED STATES, BY DECADES

Decade	Barrels (42 Gallons)
1859–1867	2,200,000
1868–1877	7,700,000
1878–1887	24,500,000
1888–1897	48,600,000
1898–1907	97,900,000
1908–1917 *	246,700,000

On the basis of a future constant consumption equal annually to the estimated 1917 consumption of 344,177,000 barrels, the estimated available reserves of 7,629,000,000 barrels would last only about 22 years, and with an increasing consumption rate per decade equal to from two to two and one half times the consumption for the preceding decade the depletion of our petroleum supply seems near at hand.

* Estimated for 1917 on basis of figures for first seven months of the year.

However, just as we become alarmed at the rapid exhaustion of our petroleum resources, information appears which indicates that there are wonderful mountains of oil-laden shales in the western states and similar shales in the east-central states, from which some 40 or 50 gallons of oil can be extracted per ton of shale. Similar processes have been carried on in Scotland for the past seventy years. The Colorado shales alone are estimated to contain some 20,000,000,000 to 30,000,000,000 barrels of oil, and for the Indiana shales estimates as high as 100,000,000,000 barrels of oil are reported. These figures indicate that our shale oil resources are enormously greater than our original petroleum resources.

TABLE XI

WORLD'S PRODUCTION OF PETROLEUM*

Country	Production in 1916: Barrels of 42 Gallons	Production in 1916: Percentage of Total	Total Production from 1857 to 1916, Inclusive: Barrels of 42 Gallons	Total Production from 1857 to 1916, Inclusive: Percentage of Total
United States	a300,767,158	65.29	3,917,328,402	60.46
Russia	b 72,801,110	15.81	1,763,583,017	27.22
Mexico	39,817,402	8.64	163,087,779	2.52
Dutch East Indies	c 13,174,399	2.86	162,174,312	2.50
Roumania	b 10,298,208	2.24	140,310,595	2.16
India	d 8,228,571	1.79	89,820,956	1.39
Galicia	6,461,706	1.40	142,494,206	2.20
Japan and Formosa	2,997,178	0.65	33,166,800	0.51
Peru	2,550,645	0.55	19,344,868	0.30
Trinidad	d 1,000,000	0.22	3,819,430	0.06
Germany	995,764	0.22	14,957,097	0.23
Argentina	870,000	0.19	1,903,121	0.03
Egypt	411,000	0.09	1,759,936	0.03
Canada	198,123	0.04	23,907,197	0.37
Italy	43,143	0.01	397,000	0.20
Other countries	d 25,000		889,513	
	460,639,407	100.00	6,478,944,229	100.00

a Marketed production. b Estimated in part. c Includes British Borneo. d Estimated.

TABLE XII

PRODUCTION AND VALUE OF PETROLEUM MARKETED IN THE UNITED STATES

	1915	1916	Per cent increase
Quantity (barrels of 42 gallons)	281,104,104	300,767,158	7.0
Average price per barrel	$0.638	$1.100	72.5
Total value	$179,462,890	$330,899,868	84.5

Uses of Petroleum

There are two general uses of petroleum—for refining purposes and for fuel.

In 1915, 227,540,000 barrels, or 82.5 per cent of all the petroleum marketed from the United States fields, went to the refineries, and 48,860,000 barrels, or 17.5 per cent of the total, were used for fuel.

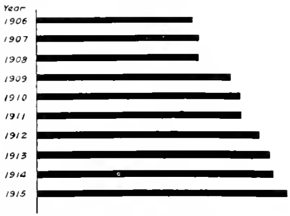


Fig. 10. The Annual Consumption of Natural Gas in the United States from 1906 to 1915. The amounts are given in Table XIV

In addition, some 16,000,000 barrels of crude oil were imported from Mexico, largely for fuel purposes.

In New England, petroleum is gaining ground as a fuel for many industries and even for domestic heating. Its use in the industries in other sections of the country is well established.

The railroads are the largest consumers for fuel purposes, having consumed 36,648,000 barrels in 1915.

Its use as fuel in the navy amounted to 1,120,000 barrels for the fiscal year ending June 30, 1916, and the United States Geological Survey estimated the requirements of the navy for the fiscal year 1916–17 as at least 1,300,000 barrels.

Gasolene

Although gasolene is not one of our natural fuel resources, its importance as a fuel warrants a brief consideration of its value. The Census Bureau Press Bulletin, February 10, 1916, shows the total quantity of gasolene produced in the United States in 1914 to have been approximately 1,236,000,000 gallons, and for 1915 the United States Geological Survey states the quantity to have been 1,977,900,000, an increase of 60 per cent. Of this total gasolene production in 1915, approximately 96.5 per cent was derived from crude petroleum, the remaining 3.5 per cent coming from natural gas. The quantity derived from natural gas is increasing very rapidly, having jumped from about 7,000,000 gallons in 1911 to 65,000,000 gallons in 1915.

Natural Gas

Natural gas, an ideal fuel, is found in twenty-three states from New York to California and from Michigan to Louisiana. In spite of extravagant waste of hundreds of billions of cubic feet and the tremendous demands upon the original supply, resulting practically in the depletion of the supply in Pennsylvania, Ohio, Indiana, and some other localities, the production in 1915 amounted to 628,579,000,000 cubic feet. As stated by the United States Geological Survey,* "the magnitude of this output . . . can perhaps be comprehended more readily by a realization of the fact that a single gas holder large enough to contain it would be one mile in diameter and 5.4 miles high."

Unfortunately no definite information is available regarding the production of natural gas prior to 1906, as meters were not in general use before that date, the gas being sold at a flat rate per day or per month.

The approximate consumption from 1906 to 1915 is shown in Table XIV and Fig. 10.

TABLE XIV

CONSUMPTION OF NATURAL GAS

Year	Cubic Feet
1906	389,000,000,000
1907	410,000,000,000
1908	405,000,000,000
1909	485,000,000,000
1910	510,000,000,000
1911	515,000,000,000
1912	565,000,000,000
1913	583,000,000,000
1914	592,000,000,000
1915	629,000,000,000

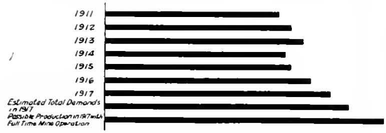


Fig. 11. The Coal Production in the United States Since 1911 Versus the 1917 Demand. The amounts in millions of of short tons are 1911, 496; 1912, 534; 1913, 570; 1914, 514; 1915, 530; 1916, 590; 1917, 640; estimated total demands in 1917, 700; and the possible production in 1917 with full-time mine operation, 800

The value of the 1882 production, the first for which any estimate is available, was $215,000, and that for 1915, $101,300,000, or 470 times that of only 33 years ago.

* "Mineral Resources of the United States," 1915, Part II, page 928, United States Geological Survey.

Of the 1915 production, 34.5 per cent was consumed for domestic purposes by over 2,000,000 customers and 65.5 per cent for industrial purposes by 18,000 customers.

Future Supply of Natural Gas

Any estimate of the possible future supply of natural gas is perhaps more of a guess than a definite calculation.

Wyer states that the average life of wells in Ohio is less than five years.

As several of the old wells are already exhausted, and as others are showing signs of exhaustion, the conclusion is that the supply cannot be counted upon for long, even though new wells are located from time to time. According to some estimates, less than two decades will see the end of the natural gas supply.

Wood

Our natural forests once covered one billion acres of ground, and in the short life of this country we have, through indifference, greed, and ignorance, used or destroyed one half of this magnificent original heritage.

The annual value of forest products is in the neighborhood of one and one half billion dollars, of which about one fifth, or about $300,000,000, is for firewood.

The extent to which we use wood in this country is perhaps best shown by the fact that our per capita consumption is seven times that of Germany and ten times that of France. For years we have been cutting timber at a rate more than three times the rate of production.

1917 Conditions

As we have had some inconvenience—in some cases real hardship—during the past winter because our immediate demands for fuel could not be met, many rumors regarding the failure of our fuel resources have been current and many statements have been made regarding the failure of the mines to produce the needed coal supply.

Let us see just what the situation was at the beginning of 1917, or just prior to our entering the war.

As shown by the figures presented, we entered the year 1917 with

(*a*) enough coal to last at least a few hundred years;

(*b*) two thirds of the original supply of petroleum;

(*c*) enough natural gas to meet the normal demand for from ten to twenty years, although failure of wells in certain districts—such as Ohio—has been most inopportune;

(*d*) one half of all the wood of the original forests.

Our present fuel problem is, therefore, not one of lack of supply at the source, but one of production, transportation, and distribution.

The pinch has been so definitely felt that it hardly seems possible that only a little over a year ago the production was greater than the demand.

What has brought about this sudden change in conditions?

1. Interruption of normal ocean transportation. The failure of ocean transportation threw back on the terminals vast quantities of freight, which, in turn, tied up cars and blocked the freight yards. Without ample cars for delivering new coal, the reserve supplies were soon exhausted and could not be replenished with any degree of regularity.

2. Impossibility of storing bituminous coal at the mines. Because of its composition, bituminous coal cannot be stored in any large quantities, due to the danger of spontaneous combustion, but must be hauled from the mines as produced. With transportation cut off, production must cease. This is not true with anthracite, and in 1916, the anthracite mines had millions of tons in storage, but the severe winter of 1916–17 seriously reduced this surplus. The spring of 1917 found us then with no reserve coal supply and with transportation seriously handicapped. Then came our entrance into the war.

3. Increased industrial demands. Although our fuel demands had been heavy prior to entering the war, the needs of the Government, of factories, and of munition plants became much more acute, many eight-hour plants jumping to twenty-four-hour service, and all at a time when car shortage and crowded terminals made delivery of coal from the mines impossible.

A popular notion prevails that the production of coal for 1917 was below normal, and that our inconvenience and suffering have been due to a failure on the part of the mine operators and miners to produce a reasonable amount of coal. An examination of the United States Geological Survey reports covering the comparative total production of bituminous coal in 1916 and 1917 reveals the facts given in Table XV.

TABLE XV

	Short Tons 1916	Short Tons 1917	Per Cent Increase
Total production of bituminous coal, January 1 to October 31 (10 months)	413,492,984	454,326,059	10.0
Total production of anthracite, January 1 to September 30 (9 months)	49,928,000	57,778,000	15.7

These show increases of 10 and 15.7 per cent for bituminous coal and anthracite respectively over the production in the corresponding months of 1916.

It should be noted that the year 1916 was a banner year for coal production in the United States, the bituminous coal output aggregating 502,500,000 tons. The bituminous production for 1917* has exceeded this amount by approximately 48,000,000 tons, or 9.5 per cent. Adding to this an estimated anthracite production of 90,000,000 tons for the year makes the total for 1917 in the neighborhood of 640,000,000,† as compared with a total of 590,000,000 for 1916.

In spite of this increased output for 1917, a reported shortage of at least 50,000,000 tons has frequently been published. This shortage is charged to the unusual demands resulting from increased industrial activity due to the entrance of the United States into the war.

But why, with such wonderful fuel resources, should there be a shortage? It is apparent that there is plenty of available fuel in the ground. It is also apparent that if the mines be worked to full-time capacity, the total production could easily be made 800,000,000 tons per year instead of 640,000,000 tons.

Why have we not had the full-time output of the mines? A brief examination of the weekly reports on the production of bituminous coal compiled by the United States Geological Survey reveals at a glance the facts in Table XVI.

This table shows clearly an increased loss of time due to car shortage since October 20th, and a marked decrease in loss of time due to labor shortage and strikes since the same date, and on December 8th, C. E. Laesher, of the United States Geological

* Estimated from eleven months' production (January 1 to November 30) of 502,100,000 tons.

† It is reported that Fuel Administrator Garfield estimates the 1917 production between 640,000,000 and 650,000,000 tons.

TABLE XVI

ALLOCATION OF TIME LOST IN PRODUCTION AND DELIVERY OF COAL IN 1917

Week Ending	Percentage of Full Time	Percentage Time Lost	Percentage of Time Lost on Account of: Car Shortage	Labor Shortage and Strikes	Mine Disability	No Market	All Other Causes	No Cause Given
October 20	65.8	34.2	11.5	15.1	2.6	...	0.1	4.9
October 27	74.9	25.1	14.8	5.9	3.8	...	0.3	0.3
November 3	75.4	24.6	14.5	5.7	3.6	...	0.3	0.5
November 10	77.8	22.2	15.3	3.6	2.7	...	0.3	0.3
November 17	75.3	24.7	19.4	2.7	2.2	...	0.1	0.3
November 24	74.2	25.8	20.2	2.2	2.8	...	0.3	0.3
December 1	74.8	25.2	18.6	2.6	4.5	...	0.2	0.3
December 8	73.6	26.4	19.3	2.5	3.9	...	0.3	0.4
December 15	57.7	42.3	30.8	3.7	6.2	...	0.9	0.7
December 22	68.1	31.9	24.8	2.6	3.6	...	0.6	0.3

Survey, writes: "It will be noted that losses due to lack of cars have been increasingly severe in the past month, rising from 11.5 per cent in the week of October 20th to 11.8 per cent for October 27th, 15.3 per cent for November 10th, 19.4 per cent for November 17th, 20.2 per cent for the week ending November 24th. Inadequate transportation facilities thus remain overwhelmingly the dominant factor limiting the output of soft coal."

Again, on December 22d, he says: "A study of these bulletins will reveal that the dominant factor limiting production is lack of transportation. So long as the soft coal mines of the country are idle from one seventh to one fifth of the time because there are no cars at the tipple, more laborers could add but little to the output. It should, however, be remembered that the railroads are already carrying more coal than ever before in the history of the country. With one exception, the production of bituminous coal during the month of November was the largest in any one month in the history of bituminous coal mining in America."

What is to be done? The coal is in the ground. It must be mined, it must be transported, it must be distributed. The necessary and natural steps seem to be:

1. Government regulation of the transportation facilities. [The railroads are now under government control.—Ed.]

2. Government regulation of the distributing agencies.

3. Government regulation of the coal mines and the labor necessary to insure production.

4. Unless the co-operation of all who operate plants—from the small household heater to the great central station—and of all who use heat, light, or power from central sources is secured for a more economical and more efficient use of fuel to bring the demand well within the reasonable productive possibilities of the mines and the transportation possibilities of the railroad and boat lines, then must follow a division of all demands into two classes, essential and non-essential—essential to the winning of the war and the vital welfare of the nation—with a positive restriction of supply to the non-essential group, even to the point of prohibition, if necessary to the one purpose now before us.

The avoidance of the drastic action set forth in item 4 calls for active service on the part of all of us in one or more of the following fields. We should, without further delay

(*a*) See that all equipment used for developing heat, light, or power is in good condition—stop the leaks, repair the insulation.

(*b*) Use approved efficient methods of firing and operating—the majority of small plants are woefully inefficient.

(*c*) Use steam economically—eliminate the waste.

(*d*) Use electricity economically—eliminate all extravagance.

(*e*) Use gas economically—burn it only when needed.

(*f*) Use power generated by economical methods—shut down inefficient plants if power is available from more efficient and more economically operated plants.

(*g*) Confine the use of heat, light, and power to the dictates of reasonable comfort and real needs—eliminate luxuries, extravagant displays, and unnecessary service.

After the War—What?

So bountiful has been our supply of fuel that we have in the past given little heed to the possibilities of the future, and our reckless waste and extravagance have been appalling. But now, at the first signs of the pinch of war, we are beginning to think—we have in a few months had a lesson in conservation which is a blessing in disguise. Let us see what our careless indifference has amounted to in the devastation of our fuel resources.

Coal

Defective mining methods have resulted in a loss varying from 50 to 150 per cent of the coal production. Our general procedure has resulted in the flooding and caving in of mines from which only the better grades of coal have been taken, and the breaking up of the seams, thus making the removal of the coal by future generations not only expensive but so dangerous as to be prohibitive. Frequently 40 or more per cent of the coal in a given mine could never reach the market. Even if only one-half ton of coal is lost for each ton marketed, which is common mining practice today, this wastage for the year 1917 would amount to over 300,000,000 tons.

Another extravagant neglect has been our failure to recover the by-products in many industrial uses of coal, as, for example, the use of the bee-hive coke oven, resulting in the annual loss of tens of millions of dollars.

Not only must we use our coal efficiently, but we must use grades not now considered commercially available—high-ash fuels, bone coals, culm, slack, lignite, and peat. The efficient use of these fuels for producer gas manufacture has already been successfully demonstrated by the United States Bureau of Mines.

Petroleum

The necessity of petroleum in the successful prosecution of the war is imperative. Petroleum has become the principal fuel of the navies of the world. All recent orders for battleships and destroyers by our navy have specified oil as fuel. The lubricants derived from petroleum are essential to the efficient operation of all types of machinery. Gasolene is required for the operation of automobiles, motorcycles, auto trucks, airplanes, armored cars, and motor boats. Our extravagant use of gasolene should be checked not only now but for all time.

The United States Bureau of Mines puts the daily production of gasolene at 6,849,000 gallons and the daily careless waste through motor cars, due to leaky carburetors, motors running idle, waste in garages and through tank wagon losses at over 600,000 gallons per day, or nearly 10 per cent of the total production. This waste is over 60 per cent of the estimated war needs, which amount to 959,000 gallons daily, and the Bureau estimates that by a little caution on our part about using our pleasure cars needlessly we can save an additional one and three fourths pints daily per car, or nearly 900,000 gallons, which, if added to the 600,000 gallons now carelessly wasted, makes 1,500,000 gallons daily, one and one half times our total war demand.

Natural Gas

Our ruthless waste of our most perfect natural fuel is beyond all comprehension.

When natural gas was first used, tremendous quantities were lost through inability to cope with the high pressures when the reservoirs were tapped. Vast quantities have been lost through the indifference of those interested in securing petroleum, but not concerned about natural gas, and the gas from the wells has been purged in order to get the oil. As great as have been the losses from these two sources, the really appalling loss has resulted from burning wells. Hundreds of millions of cubic feet have thus been destroyed daily. For 20 years, one well blew forth wasted gas, the aggregate value of which was $3,000,000. As late as 1913, in the Oklahoma field alone, the yearly waste amounted to 100,000,000,000 cubic feet, and not 10 years ago I. C. White, in speaking of the conditions in West Virginia, said: "At this very minute our unrivaled fuel is passing into the air from uncontrolled gas wells, from oil wells, from giant flambeaus, from leaking pipe lines, and the many other methods of waste at the rate of not less than 1,000,000,000 cubic feet daily, and probably more."

For years the waste was equal to the amount utilized, and frequently reached the equivalent of the loss annually of 20,000,000 tons of coal, or the destruction of a 38-ton car of coal every minute of every 24-hour day for the year.

Forests

The waste of our forest products that might be utilized for fuel is enormous. In the lumbering operations the loss is put at one quarter of the timber cut, and at the mills at least another quarter of the original forest output is sacrificed, and by the time the lumber is in the finished product fully 60 per cent of the forest growth has been ruined for commercial use. Some of this refuse is used for fuel, but a large portion is dissipated, and much is set on fire in order to get rid of it.

No doubt many of you have not forgotten the huge piles of sawdust and edgings burning at the mills day and night throughout the year.

A second tremendous waste results from our turpentining methods. The life of the boxed trees is but a few years at most, and many are blown down and left to decay in the forest.

The third and most serious loss is due to forest fires, whose annual devastation has often amounted to fifty or more millions of dollars.

Utilization of Water Resources

When our mineral fuel resources have been used they are gone forever. The supply is limited. We must reform. We must so discipline ourselves that we mine only such amounts as we really need and can efficiently use, and, to the end that these fuel resources be conserved to meet the needs of future generations, we must develop our water resources.

The surprising effect of hydro-electric power upon fuel conservation is shown by the recent electrification of portions of the Chicago, Milwaukee and St. Paul Railroad, Montana. Two divisions have been electrified, and a third will be in a few months.

As stated by the *Electrical Review*, October 20, 1917: "The conservation of 200,000 tons of coal and 800,000 barrels of oil per annum in the operation of about 725 miles of railway makes a considerable impression in the fuel supply problem. It is 18 per cent of the fuel saving effected by the reduction of passenger train service on all the railroads of the United States for the year."

True Conservation

Besides the efficient operation of plants for the production of heat, light, and power, true conservation means that:

1. We must use efficient modern methods for mining coal.

2. We must recover the by-products from coal whenever possible, and eliminate extravagant methods of making coke.

3. We must use grades and kinds of coal not now regarded as commercially available.

4. We must not use petroleum as fuel when other satisfactory fuels or other economical sources of power are available, or we will deprive future generations of the valuable and necessary products derived from petroleum.

5. We must check the needless, thoughtless waste of gasolene.

6. We must check the useless flow of natural gas from the wells and the terrible destruction caused by burning wells.

7. We must reduce the waste in cutting timber and manufacturing lumber and must utilize the unavoidable waste for fuel.

8. We must reduce fire losses in our forests.

9. We must reforest large areas and must substitute other products for timber.

10. We must generate power close to the sources of supply—at the mines—transmitting electrical energy instead of transporting the coal.

11. We must take advantage of our wonderful water resources.

This war is a terrible thing, but through its many wholesome lessons we should be brought to a realization of our past ruthless waste and extravagance, and should remember that fuel as well as food is essential to our welfare and protection. "Don't waste it."

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Radiator Tank Transformers

By H. O. Stephens and A. Palme

Transformer Engineering Department, General Electric Company

The demand for increased capacities in transformers and the desirability of having this equipment entirely self-contained brought about the development of the radiator type of transformer. The need of having the radiators oiltight required an all-welded steel construction, as cast iron was too heavy, and various space requirements necessitated a great variety and flexibility of radiator arrangement. This article describes the construction of some of the latest forms of radiator transformers.—Editor.

The most undesirable by-product of electrical transformation is heat. Depending upon the size of the transformer, the amount of heat generated varies from 1 to 5 per cent of the total output.

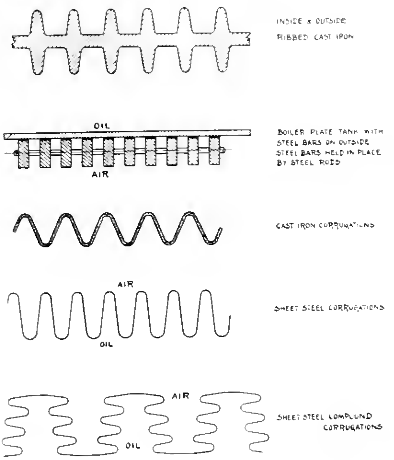


Fig. 1. Various Methods of Increasing Tank Surface

No matter what the size or the voltage of a transformer may be, its internal insulation always consists of organic materials. To maintain this insulation in first-class condition is of vital importance to the transformer as its primary function is the safe and permanent separation of two voltages. In the construction of modern transformers, the following insulating materials enter: cotton, paper, varnish, treated wood, fiber, oil, and other allied materials. Past experience has shown that transformers cannot be operated continuously above a maximum temperature of about 105 deg. C. without permanently injuring these organic materials.

If the heat generated within a transformer is not carried away properly, hot spots will soon develop in its windings. These cause more or less rapid charring of the insulation and a break-down is inevitable.

The most widely used medium for transferring heat within a transformer is oil. The oil is the "middle-man," so to speak, as it only conveys the heat from the hot transformer to some cooling agent.

Fig. 2. First Tubular Tank ever Built. Made by the Stanley Electric Manufacturing Co., Pittsfield, Mass., January, 1898

There are two distinct classes of transformers: viz., self-cooled and artificially cooled. In the former, the heat is dissipated by direct radiation and natural air circulation; while in the latter, it is dissipated primarily by forced circulation of air or water. Only the first mentioned type of transformer will be discussed in this article.

A self-cooled transformer represents a perfectly self-contained electrical unit, not requiring any attendance during its service except occasional inspection. Small transformers up to about 50 kv-a. are simply placed

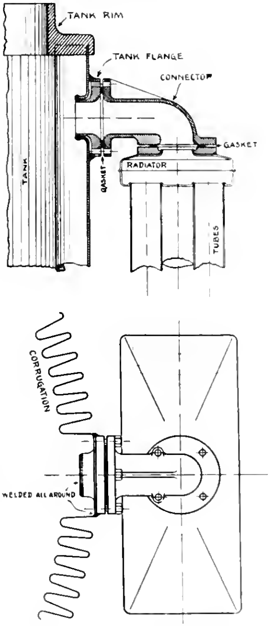


Fig. 3. Method of Attaching Radiator to Corrugated Tank

in a smooth cast-iron tank, the surface of which is sufficient to dissipate all the heat generated by the transformer. Since the mass of a transformer, and hence its loss, varies as the cube of its dimension, while the surface of the containing tank varies as the square of its dimension, obviously special means must be provided for increasing the radiating surface exposed to the circulating air as the capacity of the transformer is increased. Fig. 1 shows various means that have been used from time to time for obtaining increased surface. At the present time corrugated steel tanks are almost universally used for self-cooled transformers of moderate size.

Steel-plate tanks with external tubes in one or more rows have been used extensively for transformers from 1500 to 3000-kv-a. capacity and sometimes larger. Fig. 2 shows a tubular tank built in 1898 by the Stanley Electric & Mfg. Co., and represents the first application of this construction to transformers.

The convenience of a transformer which is entirely independent of a supply of cooling water or air, together with the ever increasing output of generating stations, soon demanded a higher limit than the one reached with tubular tanks.

The problem was to expose a reasonable volume of oil to free circulating air so as to obtain effective tank surfaces greater than could be obtained economically with a triple-row tubular tank. This was solved with the development of the radiator tank.

A radiator tank consists of a main tank to which are attached special designed radiators through which the oil circulates. A satis-

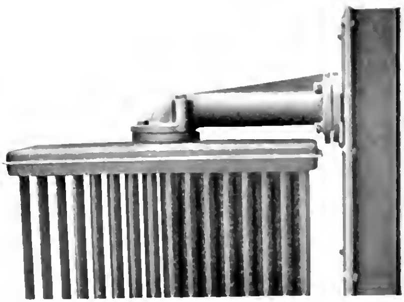


Fig. 4. Connector between Radiator and Tank

factory radiator should comply with the following requirements.

1. *It should be perfectly and permanently oil-tight.*

   It was impossible to use radiators designed for the usual hot-water or steam-heating systems because these radiators, although being water-tight or steam-tight, were not oil-tight. The solution was found in a completely welded all-steel radiator with no internal joints.

2. *It should be light in weight.*

   This eliminated cast iron and gave preference to pressed steel. The weight of the present radiator is approximately the same as its oil content.

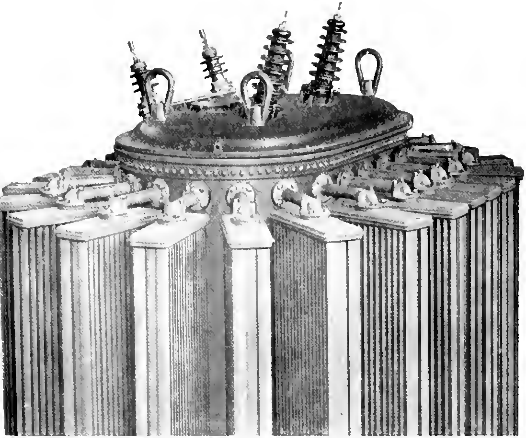


Fig. 5 Upper Part of Radiator Tank, 25-cycle, 8000-kv-a. Transformer

3. *It should be free of air pockets.*

   This means that by filling the radiator with oil no air should be entrapped in corners, etc. This is very important as the oxygen of the air in contact with hot oil not only tends to sludge the oil, but also causes a slow deterioration of the steel.

4. *It should be free from dead oil pockets.*

   Dead oil pockets in the bottom of a radiator are objectionable for the following reasons:

   (a) They reduce the effectiveness of the circulation and radiation.

   (b) They make it impossible to completely drain the oil.

   (c) They form a trap for sediment, water, acids, and other foreign material which may gradually disintegrate the walls of the radiator.

5. *It should afford free paths for the circulation of air and oil.*

   This is obtained by the use of flattened tubes welded into generous headers. The air circulates freely all around the tubes and convection currents of oil flow downward in the tubes as it cools.

6. *The radiators should be easily detachable from the tank.*

   This is necessary because in some cases the tank has to be shipped without the radiators in order to clear the railroad profile.

7. *Perfect interchangeability between the radiators is imperative.*

This eliminates marking of the radiators and facilitates replacement. It is obtained by accurate workmanship and extensive use of templets for all assembly and machining operations.

Although a number of different kinds of radiators have been built embodying some of these requirements, the result of all these requirements was a radiator built entirely of pressed steel, consisting of an upper and a lower header connected by a number of steel tubes welded between these two headers.

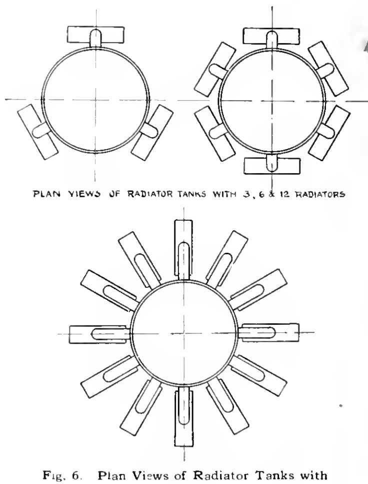


Fig. 6. Plan Views of Radiator Tanks with 3, 6, and 12 Radiators

The two headers each have one standard pipe flange welded on, whereby the connection between the tank and the radiator is made with a cast-iron elbow.

Whether the radiator is to be attached to a corrugated or a boiler-plate tank, there has to be welded thereon an intermediate flange against which the elbow is to be bolted. Thus, there are four detachable joints per radiator. However, all these joints are standard pipe flanges accommodating a gasket of special material easily giving a dependable oil-tight joint that can be made by any ordinary workman. Figs. 3 and 4 show the method of mounting a radiator on a corrugated tank. Similarly, radiators are attached to boiler-plate tank as shown in Fig. 5.

To accommodate the over-all dimensions of a transformer to special requirements, these radiators are made not only in different lengths but also with different numbers of tubes.

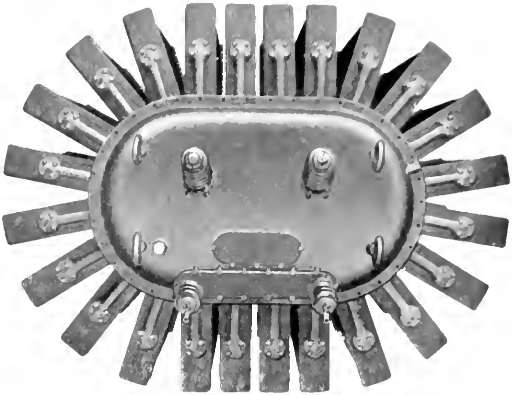


Fig. 8. Plan View of Radiator Tank, 25-cycle, 8000-kv-a. Transformer

This insures great flexibility. In other words, if a transformer requires a certain tank surface, the designer can build up this surface from a combination of three different factors; viz., number of radiators, length of radiators, and number of tubes per individual radiator. A few long radiators may give, of course, the same cooling surface as a large number of short ones.

If the number of radiators is not too great, they are arranged tangentially around the tank. Larger surfaces are obtained by a radial arrangement. Fig. 6 illustrates these constructions. In the latter case, where the weight of the radiators acts upon a longer lever, boiler plate is preferably chosen for the material of the main tank.

Heat-run tests on a great many of these radiator-tank transformers show a very high thermal efficiency of the radiators per unit surface.

Among the most prominent radiator tanks recently built by the General Electric Company may be mentioned six 25-cycle transformers, each of 8000 kv-a. single-phase output. These were by far the largest self-cooled transformers ever built. The main tank of these machines was made of boiler plate, and had 24 radiators attached. This gave a total tank and radiator surface of nearly one million square inches. Figs. 5 and 8 are two views of one of these units and show the immense radiation surface.

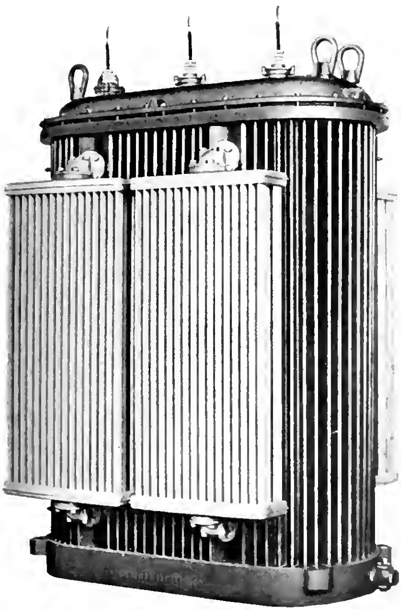


Fig. 7. 1000 Kv-a. Corrugated Tank Transformer Equipped with Four Radiators

Short-circuit Windings in Direct-current Solenoids

By O. R. Schurig

Consulting Engineering Laboratory, General Electric Company

It has long been known that a short-circuited winding surrounding a magnetic core will prolong the time taken by the flux to decay after the removal of the magnetizing force. The author of this article describes useful applications which he has made of this phenomenon in connection with the design of direct-current solenoids.—Editor.

If an iron-core solenoid is energized by direct current and is surrounded with a short-circuited winding, the decay of flux, on removal of the magnetizing force, is appreciably prolonged. A soft-iron armature held against the core of such an electromagnet in opposition to the force of a spring or of gravity will, therefore, remain in the attracted position for a longer period of time after the removal of the magnetizing current than when no short-circuited winding is used.

The period of delay can be made from a fraction of a second to five seconds or still longer by suitable design. This delay feature may be applied in a number of useful ways.

Principle of Operation

The principle involved is illustrated in the following: In Fig. 1, AA represent the

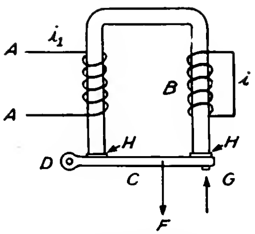


Fig. 1. Diagrammatic Sketch of Solenoid

terminals of the magnetizing winding surrounding the magnetic core shown. The winding B is placed on the same core and is short-circuited. An armature C is pivoted at D and is controlled by a force F. A direct current i_1 passing through the winding AA establishes in the magnetic circuit a certain flux which attracts the armature to the fixed core in opposition to the force F. If the current i_1 is broken when a value of flux ϕ_1 has been established, the decaying flux will induce a current i in the circuit B. This current is defined by the equation

$$o = Ri + L\frac{di}{dt} \qquad (1)$$

where R is the resistance and L the self-inductance of the circuit B under the conditions stated. In terms of the instantaneous flux ϕ, the above equation becomes approximately (if L is assumed to be constant within the range of flux considered)

$$o = \frac{RN}{L}\phi + N\frac{d\phi}{dt} \qquad (2)$$

where N represents the number of turns on the short-circuited winding B. The time in seconds required for a change of flux from an initial value ϕ_1 to a final value ϕ_2 is approximately

$$t = \frac{L}{R} logh \ \frac{\phi_1}{\phi_2} \qquad *(3)$$

If ϕ_1 is the flux in the core at the instant when the current i_1 is interrupted and ϕ_2 is the flux at which the armature is released from the core, then t represents the time interval between the instant of the removal of the magnetizing force and the instant of the release of the armature. This formula. because of the approximations made in its derivation, is not exact and is given primarily for the purpose of indicating general factors of design rather than for precise calculations.

In equation (3) the value of L, for a given set of coil dimensions, varies directly with N^2 and inversely with R, the reluctance of the magnetic circuit; while the resistance R, for a given winding space, varies directly with ρ, the specific resistance, and approximately with N^2. The value of t is, therefore, roughly proportional to

$$\frac{1}{R\,\rho}\, logh\, \frac{\phi_1}{\phi_2}$$

It follows that a slow flux decay will be obtained if the reluctance of the magnetic circuit and the resistivity of the short-circuited winding are made low, and if the ratio $\frac{\phi_1}{\phi_2}$ is made as large as possible. This requires

* "logh" signifies hyperbolic logarithm, or logarithm to the base ϵ (=2.718).

(1) A magnetic circuit of a good grade of soft iron and of large cross section.

(2) A minimum length of non-magnetic gap in the magnetic circuit.

(3) Low retentiveness of the iron.

A simple and effective form of short-circuit winding is a copper tube of heavy wall slipped over the core and covering a large portion of its length, the magnetizing winding being placed around the copper tube.

Construction and Applications

It is frequently desired to delay the opening of a direct-current solenoid after its magnetizing current has been removed. Such requirements occur in the design of direct-current relays, circuit-breakers, etc. On the basis of the principle just described, a copper ring surrounding the path of the flux, or a short-circuited winding, may be used to accomplish the delay. In a particular iron-clad solenoid of the plunger type, Fig. 2, a copper tube *A* of 0.84 in. (2.14 cm.) internal diameter, 0.5 in. (1.27 cm.) thickness of wall, and 2.56 in. (6.50 cm.) length was employed, the tube fitting loosely over the iron plunger *B*. The total non-magnetic gap in the magnetic circuit, with the plunger drawn against the stop *C*, was 45 mils (1.1 mm.), one-third of which was represented by a phosphor-bronze washer *D* placed between the plunger and its stop, the remainder being between the plunger and the iron case, at *E*. In this model the plunger was released about one second after the removal of the magnetizing force, the weight of the plunger acting in opposition to the magnetic pull.

A considerably longer time of delay can be obtained in a horse-shoe type of electromagnet, because its magnetic circuit can readily be made with a lower reluctance than that of the gravity controlled iron-clad type. A diagram of the horse-shoe type is shown in Fig. 1. By equipping the armature *C* with a make-and-break contact *G* connected in series with the magnetizing winding *A*1, the armature is attracted to the core shortly after having been released. In this manner, a continuously repeated cycle is performed with a period depending on the intervals required for magnetization and for demagnetization.

This form of solenoid can be applied to give a uniformly recurring signal, such as the flashing of a light, the ringing of a bell, etc. With the aid of a dry battery it can be made self-contained, self-starting, and continuously operating, and should be useful, for instance, for buoy lighting in navigation. A model constructed to give a total period of five seconds, with a period of magnetization of about 0.3 seconds, was of the horse-shoe type, Fig. 1. It has two similar copper short-circuiting rings, one on each leg of the core

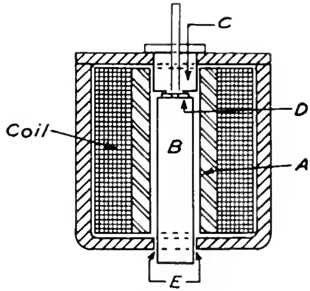


Fig. 2. Iron-clad Solenoid, Special Retarding Construction

with half of the magnetizing winding surrounding each copper ring. A helical tension spring is attached to the armature, pulling in a horizontal direction at *F*. The principal dimensions are:

Length of each leg of iron core	= 5	in.	12.7 cm.
Diameter of core	= 0.75	in.	1.91 cm.
Wall thickness of each copper tube	0.625	in.	1.52 cm.
Length of each copper tube	= 4.5	in.	12.45 cm.
Thickness of each non-magnetic pole face cap, *H*	5	mils	0.13 mm.
Distance between axes of copper tubes	= 4	in.	10.2 cm.

The total period of this relay may be varied between the limits of 2 and 8 seconds by adjusting the stroke of the armature, the magnitude of spring tension *F*, the separation of the contacts at *G*, and the magnetizing force.

Since not only the decay of flux but also its building up is retarded by the short-circuiting rings, the cycle of operation may be changed if a low voltage is impressed on the magnetizing coils, if the stroke is made large, and if the separation of the contacts at *G* is increased. In this case, the field flux will build up slowly and the contact at *G* will have to remain closed for a longer time (up to several seconds), while the lower initial magnetization will reduce the interval of flux decay and result in an early release of the armature.

Variations in Operation

Since the temperature affects both the permeance of the magnetic circuit and the conductance of the short-circuit winding, the length of the delay period will be a function of the temperature of these parts. An increase of temperature shortens the period if a copper short-circuit winding is used.

Any vibration or jarring will also shorten the period, because such disturbances accelerate the demagnetization of the iron. It follows that great precision in the delay period cannot be expected unless special care is taken to maintain uniform conditions.

Summary

(1) A short-circuited winding placed on a direct-current solenoid causes a slow decay of the flux in its core and causes an armature to be held against the core for an appreciable period after the magnetizing current is cut off.

(2) This period is roughly proportional to the permeance of the magnetic circuit and to the conductance of the short-circuited winding, and increases with an increasing ratio of maximum to minimum flux.

(3) An effective form of short-circuit winding is a thick copper tube surrounding the path of flux.

(4) A copper tube of 0.5 inch (1.27 cm.) wall thickness placed around the core of a certain iron-clad plunger type of solenoid caused a delay of about one second in the release of the plunger from its stop.

(5) Two copper tubes of 0.625 inch (1.52 cm.) wall thickness embodied in a specially constructed horse-shoe electromagnet caused a delay period of 5 seconds.

(6) An electromagnet of this type operated by a dry battery can be employed for periodically flashing a buoy light for use in navigation.

(7) By suitable design the operation of such an electromagnet can be made continuous and the mode of its cycle can be varied over wide limits; viz., the magnetization period can be made from 5 per cent to 50 per cent of the total period.

(8) The length of the total period is affected by temperature changes and by jarring of the apparatus.

Reactance and Short-circuit Current

By R. E. Doherty

Alternating Current Engineering Department, General Electric Company

The usual dissertation on the quantitative effect of reactance on short-circuit current is highly technical and requires a proficiency in higher mathematics and complex functions for its ready comprehension. At our request, Mr. Doherty has written the following article to explain the inter-relationship of reactance and short-circuit current in an easily understandable manner.—Editor.

When an alternator is suddenly short-circuited the current wave may be as shown in Fig. 1, that is, symmetrical about the zero axis, or it may be shown in Fig. 2 in which the wave, although of practically the same amplitude, is completely offset either above or below the zero axis, or it may be partially offset between these two limits, as shown in Fig. 3. Any one of these conditions may occur under the same terminal voltage (as read by a voltmeter) existing before short circuit, *its occurrence depending only upon the instant at which the short circuit takes place.* That is, the wave of current will be symmetrical, as shown in Fig. 1, if the short circuit occurs at the instant of maximum phase voltage; and will be completely offset, as in Fig. 2, if the short circuit occurs at the instant of zero phase voltage. Obviously, between these conditions, the wave will be partially offset, plus or minus, depending upon the sign of the voltage half wave during which the short circuit occurs.

Under any of these conditions the self-inductive reactance is practically the same. Hence some confusion has arisen regarding the relation between reactance and short-circuit current.

Ordinarily the *initial* short-circuit current is calculated by

$$I_o = \frac{E}{X_o}$$

where

I_o = effective value (as read on ammeter) of initial short-circuit current which occurs when the current wave is symmetrical about the zero axis, as shown in Fig. 1.

E = effective value (as read on voltmeter) of phase voltage (per leg) existing before short circuit.

X_o = total self-inductive reactance per phase (per leg) in ohms. This includes the self-induction of both field and armature circuits, and should be called *transient reactance*.*

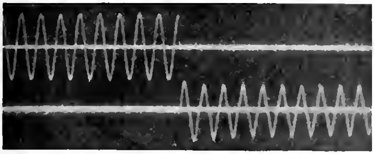


Fig. 1. Short Circuit Occurring at Instant of Maximum Phase Voltage. Current wave symmetrical about the zero axis. Upper wave, phase voltage. Lower wave, short-circuit current

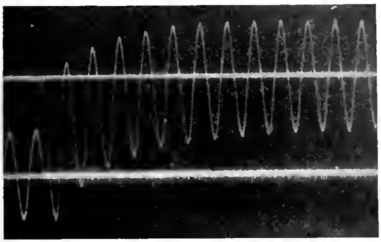


Fig. 2. Short Circuit Occurring at Instant of Zero Phase Voltage. Wave entirely offset. Upper wave, short-circuit current. Lower wave, phase voltage

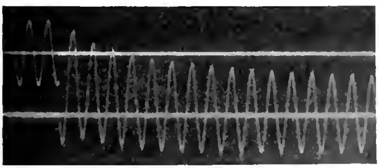


Fig. 3. Short Circuit Occurring at About 85 Per Cent Maximum Voltage. Wave partially offset. Upper wave, phase voltage. Lower wave, short-circuit current

If the circuit contains a reactance X_{ex} external to the generator, as shown in Fig. 4, the inital short-circuit current will be

$$I_o = \frac{E}{X_o + X_{ex}}.$$

Assuming that the current wave, Fig. 1, is a sine wave, the crest value will be

$$\sqrt{2}\, I_o \text{ amperes.}$$

If the wave happens to be entirely offset, as in Fig. 2, the first crest value will be approximately (actually less)

$$2 \times \sqrt{2}\, I_o.$$

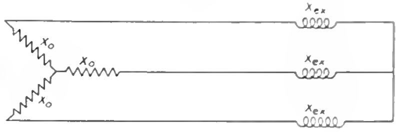


Fig. 4

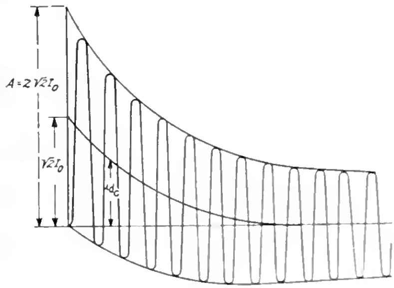


Fig 5

because the amplitude A of the wave, Fig. 5, as measured between crests, is the same in either case. That is, in either case there is an alternating wave of the same magnitude. *It is the effective* (r.m.s.) *value of this alternating wave which is always associated with the reactance,* X_o. When the wave is offset it means that in addition to the alternating wave, there is a direct current, i_{dc}, Fig. 5; and obviously the value of the direct current, which may have any initial value between zero and $\sqrt{2}\, I_o$, is the offset. The alternating wave has been aptly called the *alternating component* of the short circuit current; the direct current, the *direct component*; and the sum of these two components, the *wave of total current*.†

Both the alternating and direct components decrease after short circuit, as shown in Figs. 1 and 2. The direct component entirely disappears in about ½ second, and the alternating component decreases to a constant, or "sustained," value in about 2 seconds. While the initial value of the alternating component may be from 10 to 15 times normal

* Durgin & Whitehead, Trans. A.I.E.E. Vol. 31, p. 1662. F. D. Newbury, Elec. Journal, April, 1914, p. 196.

† Hewlett, Mahoney, and Burnham, Proc. A.I.E.E., Feb. 1918, p. 46.

current, the sustained value is usually only two to three times normal.

The initial, effective value of the *alternating component* (during the first cycle or so) is the value, I_o, which is given by

$$\frac{E}{X_o}$$

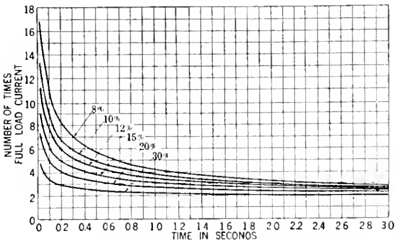


Fig. 6. System Short-circuit Characteristics—8, 10, 12, 15, 20, and 30 per cent total reactance based on total kv-a. rating of synchronous machines. Time-current Curves—r.m.s. current in terms of total full-load current of machines—initial full load at 0.8 power factor assumed

or, if there is external reactance, by

$$\frac{E}{X_o+X_{ex}}$$

With the voltage and reactance given, the above relations make it possible to obtain any of the particular values of current that may be desired.

Take an instance:

1000 kv-a., 2300-volt, Y-connected generator.

10 per cent transient reactance. External reactance, 10 per cent.

Voltage per leg $=2300\div\sqrt{3}=1330$ volts.

Normal current $=250$ amperes.

Transient reactance $X_o=$

$$\frac{0.1\times 1330}{250}=0.53 \text{ ohms.}$$

External reactance $X_{ex}=$

$$\frac{0.1\times 1330}{250}=0.53 \text{ ohms.}$$

Effective, initial value of *alternating component* is

$$I_o=\frac{E}{X_o+X_{ex}}=\frac{1330}{0.53+0.53}=1250 \text{ amp.}$$

This could have been obtained directly from the fact that 20 per cent total reactance would give an initial effective value of alternating component equal to five times normal current.

The crest value of the alternating component is

$$\sqrt{2}\,I_o=\sqrt{2}\times 1250=1765 \text{ amperes.}$$

The initial value of the direct component is equal to the crest value of the alternating component, and is therefore 1765 amperes.

The maximum possible instantaneous value, which occurs approximately at the end of ½ cycle after short circuit, is the sum of the direct component and the crest value of the alternating component. It is approximately

$$2\sqrt{2}\,I_o=3530 \text{ amperes.}$$

Different engineering problems involve different values of short-circuit current, but there is one point which applies to them all. The wave may be completely offset; hence calculations should assume that condition. Mechanical stresses in certain cases are based upon the maximum possible crest, viz.,

$$2\sqrt{2}\,I_o=(1765 \text{ amp. in example above}).$$

The rupturing capacity of circuit breakers and the heating of circuits are based upon the effective, or r.m.s.* value of the wave of total current. For the first cycle or so, assuming that the current does not decrease, the r.m.s. of the total current is

$$\sqrt{3}\,I_o=(2160 \text{ amp. in example above}).$$

There is, of course, some decrease during this time, hence the value $\sqrt{3}\,I_o$ is slightly too

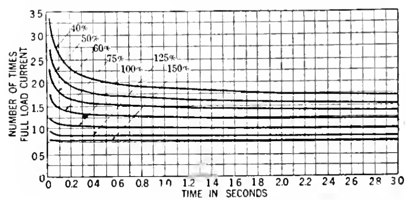


Fig. 7. System Short-circuit Characteristics—40, 50, 60, 75, 100, 125, and 150 per cent total reactance based on kv-a. rating of synchronous machines. Time-current curves—r.m.s. current in terms of total full-load current of machines—initial full load at 0.8 power factor assumed

high. Hewlett, Mahoney, and Burnham† have published curves giving the r.m.s. of the total wave for any time between the instant of short circuit and 3 seconds after. These curves, Figs. 6 and 7, were based on average values from oscillographic data.

* "Root mean square" value. The heating of a circuit depends upon the square of the current in the circuit. Hence the heating effect of an alternating current or of a pulsating current is obtained by taking the mean of the squared instantaneous values of the alternating or pulsating wave. The square root of this mean is called the effective value of current, and is the value which is read on an ammeter.

† Proc. A.I.E.E. Feb. 1918, p. 48.

Static Condensers

By W. B. Taylor
Lynn Works, General Electric Company

Unity power-factor on a transmission system is a condition devoutly to be wished, but one which is seldom realized except on direct-current circuits. Low power-factors entail heavy idle currents which increase heating and line losses and disturb voltage regulation. Wherever possible some means should be employed to correct this condition; the usual method being the installation of synchronous condensers. These machines, however, are relatively expensive and require the services of an attendant, and in many instances the cost of installation and maintenance is not justified. The static condenser offers a solution of the problem in many such cases. This article shows the improvement in service that may be effected by the use of static condensers on circuits of low power-factor, and compares this improvement with that afforded by installing additional feeder copper.—Editor.

In the generation, supply, and use of alternating current one feature or property, often overlooked by those familiar with direct-current work, is the power-factor of the apparatus converting the electrical energy into mechanical work.

For alternating currents, instead of merely multiplying the volts by the amperes to get the energy consumed, as in a direct-current circuit, this product must be multiplied by a further constant indicative of the reactive character of the circuit. This constant is called the power-factor.

If, therefore, there is no reactance in the load circuit, as is the case with incandescent lamps or transformers fully loaded with incandescent lamps, the energy is represented by the product of the volts and amperes, the factor being, of course, unity.

When, however, there is much reactance in the load circuit, as in the case of lightly loaded alternating-current motors, the generators and supply circuits must deliver the current required to energize the motor reactance as well as supply the actual power delivered by the motor. Thus, ignoring the motor losses, the volt-amperes supplied must

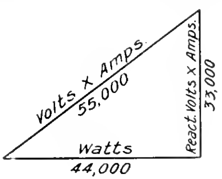


Fig. 1

be multiplied by a factor of 0.9, 0.8, or even 0.7 to determine the actual energy represented.

To take a concrete example:

Amperes required by motor or feeder	100
Voltage of circuit	550
Wattmeter reading	44,000

The power-factor is therefore 44,000 divided by 55,000, or 0.8, as shown diagrammatically in Fig. 1.

In other words, the generator and the transmission lines, transformers, and feeders must in this case supply twenty-five per cent

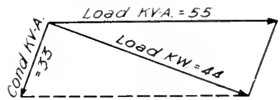


Fig. 2

more volt-amperes than the motor (ignoring losses) turns into useful work. It must be borne in mind in this connection that the steam turbine or other prime mover has to supply only the actual energy, or in this case 44 kw., but the generator and lines must supply, with corresponding heating, line drop, etc., the 55 kv-a.

It will be appreciated that any device which will neutralize the effect of the reactance will stop this drain on the supply system.

A static condenser has just this desired property, in that its current is leading instead of lagging, and if a 33 kv-a. condenser were connected near the load in the instance referred to above, the supply system would have to furnish only the 44 kv-a. required. This is shown in Fig. 2, the 33 kv-a. reactive component being neutralized by a 33 kv-a. condenser.

For a circuit having other constants the size of the static condenser required to partially or completely neutralize the reactance is similarly determined.

Kv-a. Capacity Saved by Condensers

Fig. 3 was prepared from various commercial feeder constants, and reference to it gives the proper size of static condenser to produce various desirable improved operating conditions.

Thus, if a certain 500-volt, a-c. feeder has a current of 500 amperes, and the power-factor shown by the power-factor indicator is 0.60, the condenser required to raise the power factor to 0.70 will be found from the figure as follows:

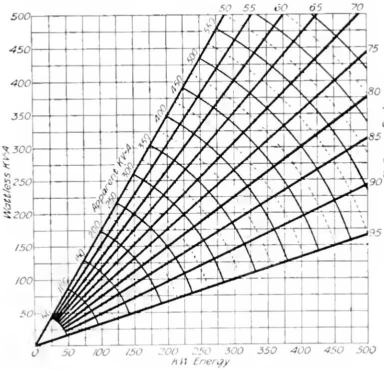


Fig. 3. Curve showing Relation of Energy Load to Apparent Load and Wattless Components for Different Power-factors

Locating on the 0.6 p-f. line the point corresponding to 250 kv-a., it is noted that the wattless kv-a. is 200 and the energy kv-a. is 150. Now as the energy is unchanged, we note the intersection of the 150 energy ordinate with the 0.7 p-f. line and find that the wattless kv-a. for this value is 153. Subtracting 153 from 200 it is found that 47 kv-a. is the exact condenser kv-a. required to raise the power-factor of this circuit from 0.6 to 0.7; correspondingly the transmitted line kv-a. is, without change of energy, reduced from 250 to about 214, or over 14 per cent.

Likewise on this feeder

an 88 kv-a. condenser would raise p-f. from 0.6 to 0.8

or 127 kv-a. condenser would raise p-f. from 0.6 to 0.9

or 200 kv-a. condenser would raise p-f. from 0.6 to 1.0

These data tabulated are as follows:

Desired Power-factor Improvement	Required Condenser Kv-a.	Reduction in Line Kv-a.	Condenser Kv-a. per Line Kv-a. Saved
0.6– .7	47	36	1.3
0.6– .8	88	63	1.4
0.6– .9	127	83	1.5
0.6–1.0	200	100	2.0

As unity power factor is approached it will be observed that a relatively large amount of condenser capacity is required for a slight saving in line kv-a.

This is graphically shown in Fig. 4, indicating that on account of cost it is not commercially desirable to attempt to raise the power-factor of a circuit much above 0.90.

Decreased Line Losses

The decrease in feeder or generator kv-a. greatly reduces the line losses. For instance, comparing the 0.6 and 0.9 cases cited above, the line losses in the feeder between the condenser and the generator, being proportional to the square of the respective currents, would be in the relation of 500 squared (250,000) to 334 squared (111,556). The losses with the condenser in operation are therefore 55 per cent less than when no condenser is used, resulting in cooler feeders, transformers, and generators.

Improved Voltage Regulation

In the same manner the voltage drop in the line is reduced 33 per cent, thus increasing motor and lamp voltages and improving generally the regulation of the system.

A very positive indirect improvement has been found in the reduced exciter current

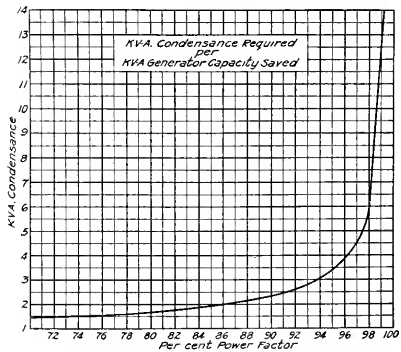


Fig. 4. Kv-a. Condensance Required per Kv-a. Generator Capacity Saved

necessary to hold normal line voltage. Thus, one customer found that his exciter output when operating without condenser at a switchboard power-factor of 0.54 was 16.3 kw. When the condenser was thrown onto the circuit, raising the power-factor to

0.85, the regulator on the exciter reduced the exciter current so that only 12.8 kw. excitation was required, a saving of over 21 per cent.

Condenser Near Load

As the condenser reduces the line current between itself and the generator, it will be appreciated that the best results will be secured with the condenser connected near the center of the load and not near the generator.

A definite illustration may serve to emphasize the various features in connection with the installation of static condensers, showing the saving in generator capacity (most important at peak load) as well as the actual saving in watts lost in lines and transmission apparatus.

Typical Case

An electric light and power company or mill organization has its power house say one mile from the center of the load on a certain feeder. Various small amounts of power are taken from this feeder at points between the center of the load and the power house and beyond the center of the load, the circuit feeding 550-volt a-c. motors or other devices. The feeders are all 300,000 circular mil cable, two cables per phase being in parallel.

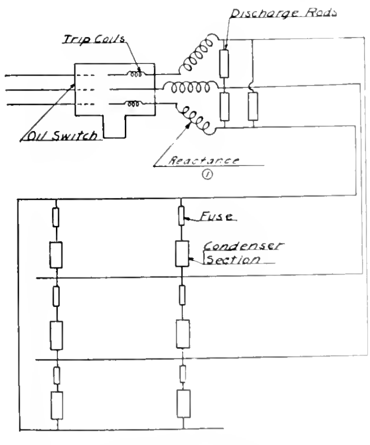


Fig. 5. Diagram showing Methods of Connecting Condenser Sections to Line

The management find that the generators have to be operated at 639 volts to give 550 volts at the center of the load. They also find that the feeder requires 232 kv-a., the actual energy being only 153 kw.

At times of peak load the station capacity is severely taxed, yet with a growing demand

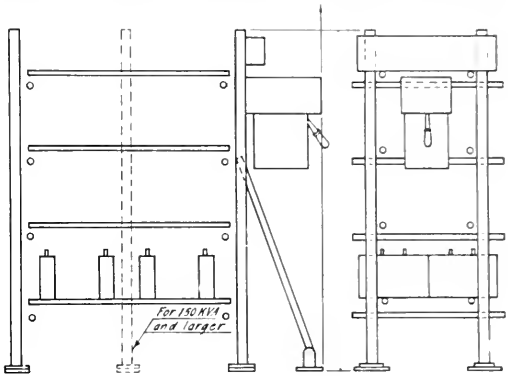


Fig. 6. Method of Mounting Condenser Section

for service the generators must be given some relief. As the relatively large investment for additional standard generators seems unwarranted, the two most promising methods are either the running in of a parallel circuit of 400,000 circular mil cable or the installation near the center of the load of a 75 kv-a. static condenser. The former of these methods, although reducing the line loss to 5.7 per cent, as shown in the following tabulation (the same value as secured by the installation of the condenser), only relieves the generators to the extent of 11 kv-a., whereas the static condenser method would relieve the generators of 60 kv-a., or about 25 per cent of their load.

Solution 1. More Copper. The additional 400,000 circular mil cables would cost approximately $1200, but the capitalized saving in line losses would be about $3600. By crediting the new arrangement with the 11 kv-a. generator capacity saved, at $10 per kv-a., the cost of the cable would therefore be $190 more than the benefit secured.

Solution 2. Static Condenser. The installation of a 75 kv-a. static condenser near the center of the load would cost approximately $1125. There would be a credit of $600 because [illegible] saved. The improvement in losses would be the same as with method 1, the net saving representing an investment of $3075.

Comparison of Methods 1 and 2. As shown above, the expenditure for cable with method 1 was $490 *more* than the benefit secured, whereas with the condenser there is a gain of $3075, making the condenser method under the conditions assumed more advantageous by $3565 than the cable relief method.

Fig. 7. Control Pedestal for 100-kv-a., 550-volt, 60-cycle, Three-phase Subway Static Condenser. Lynn Gas & Electric Company

In the above typical case nominal values of interest, charges, etc., were assumed, viz.:

Value of kilowatt-hour	$0.01
Hours operation per year	7200
Interest rate	10 per cent
Generator cost per kv-a.	$10.00

Therefore it will be appreciated that for other conditions, values, etc., the net advantage of using the static condenser can be determined by substituting the new values in place of those used.

Even though the exact value of the energy saved is ignored in comparing solutions 2 and 3, it will be observed that the difference between the assumed cost of the condenser ($1125) and the value of the generator economy ($600) is $525. The difference between the cost of the lines ($4200) and the value of its generator economy ($110) is $4090. The financial advantage, therefore, of the condenser method is represented by the difference, or $3565.

The static condenser method is accordingly more advantageous by $3565 than the installation of additional cable to secure the same line loss under the conditions assumed.

General

The static condensers have no revolving parts and require practically no attention beyond the throwing of simple control switches.

The active materials of the sections are sealed in substantial tin boxes, approved enclosed fuses being used to connect the individual sections to their respective connection bars.

The individual sections are mounted on a pipe frame work using the general switchboard clamping devices, as indicated in Fig. 6. The illustration likewise shows the control oil switch mounted directly on the rack, and the series reactive coils just above the switch, and also the discharge rods, which in this case are mounted just above the sections.

The series reactive coils are used as a screen to exclude from the condensers any higher harmonics which may exist in the voltage wave or which may be impressed by line disturbances. This feature is fully covered by the manufacturer's patents.

The discharge rods are placed across the various busbars so that when the oil switch is open the condensers will discharge through these resistances, and so return to a neutral condition ready for the unit to be reconnected to the circuit.

Though condensers are designed for 24-hour service some of our customers find it advantageous to disconnect the units from the line at night, and reconnect them in the morning. The transmission lines are then not loaded up with high leading currents at night, with unnecessary C^2R losses which are just as disadvantageous at night as high lagging currents are during the day.

OPERATING CONDITIONS WITH AND WITHOUT STATIC CONDENSERS

3-phase—60 Cycles
550 Volts at Center of Load
Center of Load one mile from bus bars

Case	1	2	3
Conditions	2–300,000	2–300,000 and 1–400,000	2–300,000
	No cond.	No cond.	With cond.
Load			
Kilovolt-amperes	200	200	200
Power-factor	0.70	0.70	0.70
Kilowatt	140	140	140
Cond. Kv-a.	0	0	75
Transmitted			
Kilovolt-amperes	200	200	156
Power-factor	0.70	0.70	0.90
Kilowatt	140	140	140
Line Loss Per Cent	9.4	5.7	5.7
Generator			
Volts	639	608	609
Kilovolt-amperes	232	221	172
Power-factor	0.66	0.67	0.86
Kilowatt	153	148	148

Saving No. 3 and No. 2 vs. No. 1		
Generated kilowatt	5.0	5.0
7200 hours at 1 cent	$360.00	$360.00
Capital at 10 per cent	$3600.00	$3600.00
Generator kilovolt-amperes	11	60
Value at $10	$110.00	$600.00
Cost of New Lines	$4200.00	
Cost of Cond. at $15		$1125.00
Net Saving vs. No. 1	$490.00 (More)	3075.00
Net advantage of condenser vs. additional lines		$3565.00

Fig. 8. 60-cycle, 50 kv-a., 550-volt Subway Static Condenser with Reactance

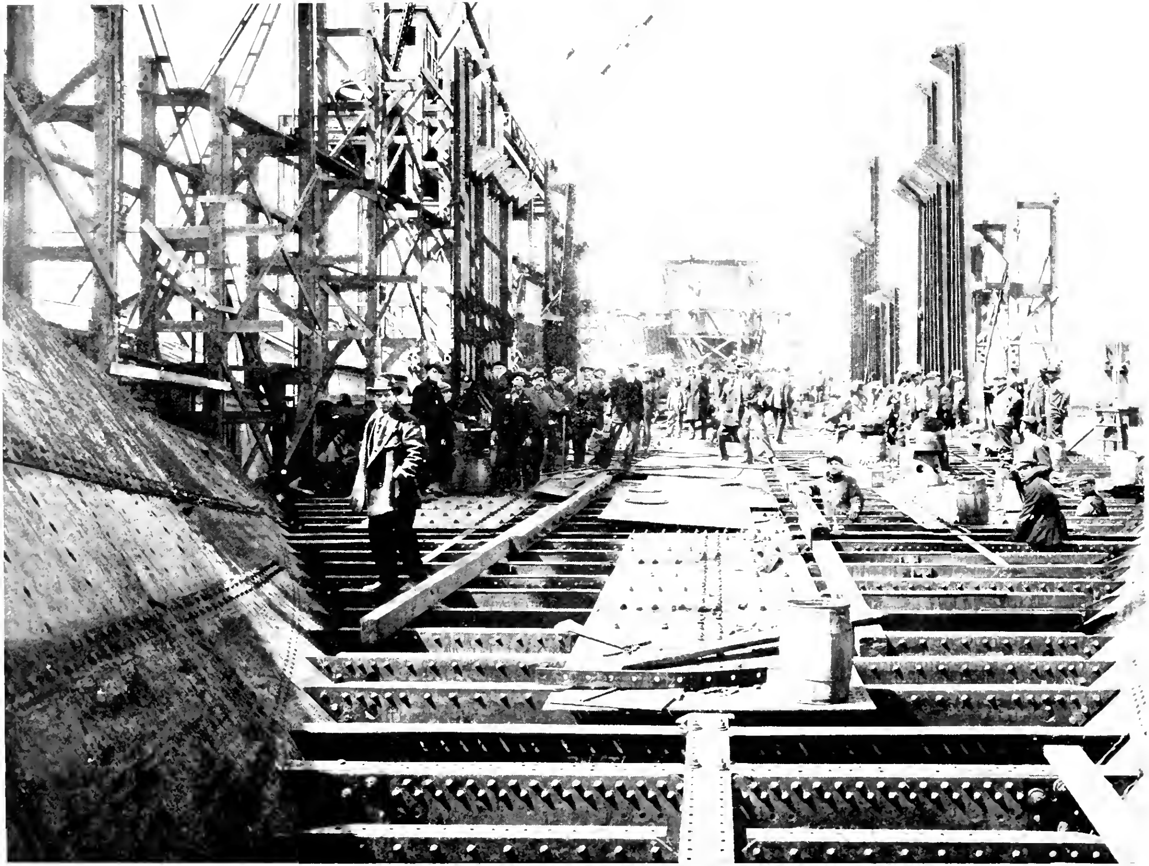
Phase of Circuit: The construction of the sections makes it possible to readily connect static condensers for single-phase operation or to arrange the active parts in groups for polyphase operation.

Frequency: As is well known, the current in a condenser with a given voltage is dependent upon the frequency; therefore static condenser outfits become relatively expensive per kv-a. at frequencies less than 40 cycles.

Voltage: Condensers can be built for operation at any commercial voltage, but it has been found preferable to use transformers or auto transformers for voltages below 1000 volts.

Capacity: Although there is no limit to the size of static condenser outfits, as this is merely a case of adding condenser sections to get the total kv-a. required, it has been found that most conditions are best taken care of by two or more units of the following capacities, which are considered the standard sizes

250 kv-a.	200 kv-a.	150 kv-a.
100 kv-a.	50 kv-a.	25 kv-a.



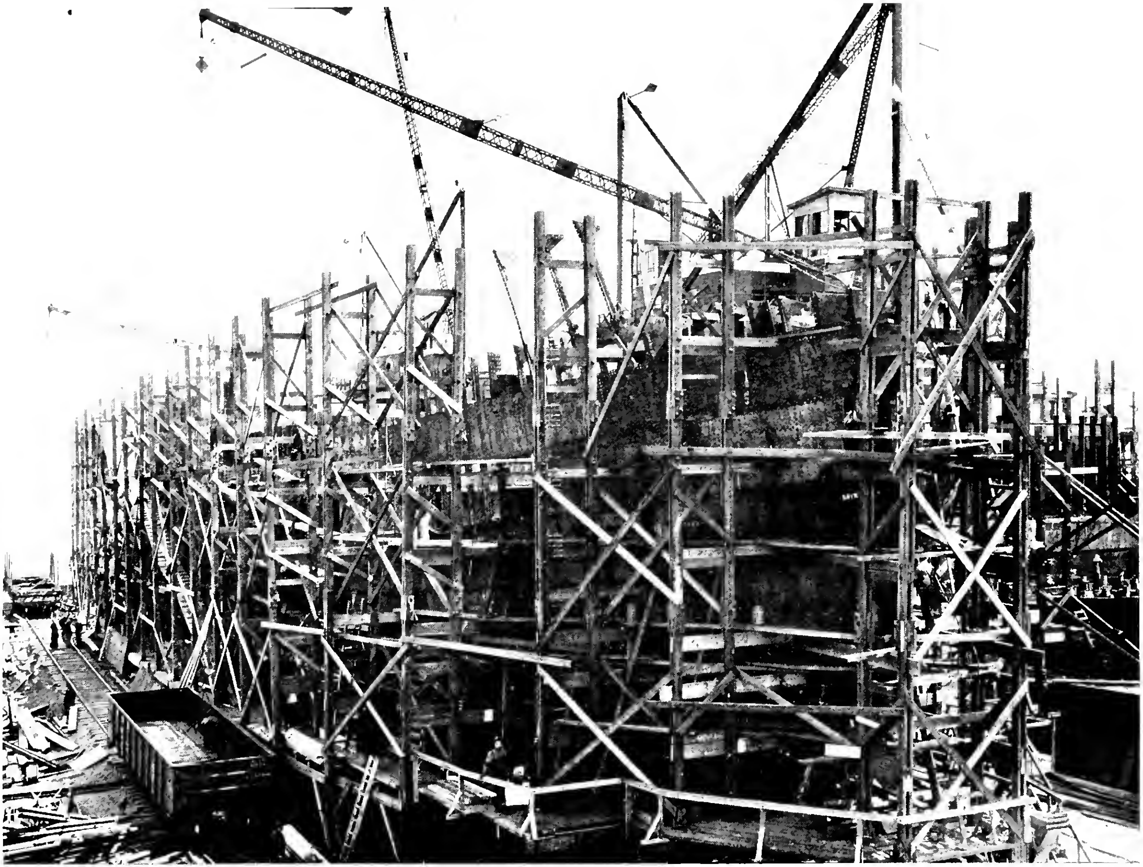
THE FABRICATED SHIP

The electrical industry is taking a leading role in the construction of America's emergency fleet. A large number of these vessels are to be propelled by steam turbines driving through reduction gears, and as is generally known, to the electrical industry belongs the

Looking forward from the stern. To right and left is seen the curved plating of the shell. On each side, in the middle distance, stand a number of side frames, and at the bow, nearly a hundred yards away, rises a bulkhead. Bulkheads are usually put together on the ground and dropped into place all complete.

[illegible] country. Another important appli[illegible] shipbuilding [illegible] the substitution of electric welding for rivet[illegible] plates, the process having great possibilities over the older

[illegible] At the [illegible] many [illegible] which are heated in long furnaces and bent to shape [illegible] have been erected. The [illegible] aft."



method in expediting the work. These contributions of the industry to the cause are additional to the equipments for lighting and steering, intercommunication and wireless, etc., that have been developed by electrical engineers and are the part of every modern vessel.

Photographs by M. Rosenfeld, N. Y. *Engravings by Sea Power*

Four fifths plated and going along merrily. Railroad tracks run down to each ship and the parts made in the 282 plants east of the Mississippi may be lifted from car to ship by the numerous cranes. With rivet construction some half million rivets must be driven in each vessel of this size.

Demand Meters

By J. A. Laubenstein

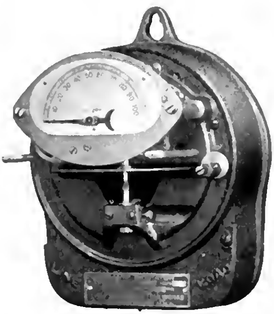
Fort Wayne Works, General Electric Company

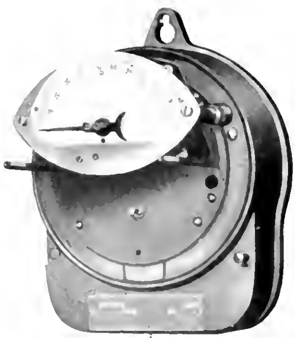
In the February 1918 issue of the General Electric Review, page 148, appeared a discussion of some factors affecting the determination of the maximum demand rate of charge for power. The article below gives consideration to the actual measurement of "demand" and describes various types of meters designed for the purpose.—Editor.

In order to obtain a basis for charge on a demand rate, it is necessary that there be some kind of device that will give an indication or record of the maximum demand of a particular installation during a stipulated period of time, such as a week or a month.

The devices used for this service may be classified roughly as follows:

(1) Demand limiters.
(2) Devices for indicating or recording instantaneous maximum demand, such as indicating and recording watthour meters and ammeters.





Figs. 1 and 2. Alternating-current and Direct-current Demand Meters. Register demand only

(3) Devices for indicating or recording the integration of power consumed over definite time intervals.
(4) Devices for indicating or recording lagged and logarithmic values of demand.

Since the meter code of the N.E.L.A. defines the "maximum demand" of an installation or system as the greatest demand measured, not instantaneously, but over a suitable and definite time interval, a consideration of the specified devices designed to measure demand is in order.

The devices of General Electric manufacture which are designed to register or record maximum demand as defined above may be classified as follows:

(*a*) Those which indicate the demand.
(*b*) Those which record the demand together with the time at which the various demands (including the maximum) occurred.
(*c*) Those which print a record of the demand together with a record of the time upon a suitable tape or paper ribbon.

All of these various classes or types of demand meters are designed to be used in conjunction with watthour meters, the registering mechanisms of the demand meters being electrically operated by means of contacts mounted on the registers of the watthour meters, suitable means being provided for establishing the time interval.

The devices in Class *a* are illustrated in Figs. 1 and 2, and give an indication of demand only, no record of time being available. The type of device shown in Fig. 1 is designed for use on alternating-current circuits and consists of a registering mechanism and a constant-speed motor mounted on a common base. The registering mechanism is actuated by the movement of the armature of a solenoid which is electrically connected to the contact mounted on the watthour meter register. The motions or impulses of the armature are transmitted to a pusher or driving dog by means of a ratchet and dog which drives the pusher through a gear reduction. The pusher engages a loose pointer mounted on the same shaft and drives the pointer to a position determined by the watthour meter speed. The constant-speed motor drives what is known as an interval cam at a definite rate of speed; and by means of a lever resting on this cam, a sliding pinion on one of the shafts of the registering mechanism is slid out of mesh sufficiently to allow the pointer pusher to return to the zero position. After a short time the loose pinion is again slid into mesh and the pointer pusher again advances. Thus, the time interval is established by the returning of the registering mechanism to zero periodically after the elapse of a definite interval of time. It will be seen that a registration of demand for the time interval has also been obtained, the value of demand being indicated upon a suitably divided scale over which the demand pointer moves.

Fig. 3. Demand Meter which Records Demand and Time at which Demand Occurs

The constant-speed motor of the foregoing demand meter for alternating-current circuits is of special design in which the speed of rotation is unaffected by variation of voltage, frequency, wave form, and temperature over very wide limits.

The type of demand meter shown in Fig. 2 is essentially the same in operation and construction as that shown in Fig. 1, except that it is designed for use on direct-current circuits and the constant speed induction motor is replaced by a spring-driven key-wound eight-day clock movement which is used to establish the time interval.

The Class (*b*) of demand devices of the block-interval characteristic takes in the type shown in Fig. 3. These devices not only register and record the demand, but also the time at which the demands occur. The record is made upon a circular wax-coated chart which is designed to rotate at a constant rate.

A steel stylus carried at the end of an arm moves radially over the chart. The tension of this stylus against the chart breaks down the air cells in the wax coating, thus causing the wax to become transparent and to show the colored backing of the paper as marks or scratches on the chart.

The registration or movement of the stylus arm is obtained in a manner similar to that employed in the type shown in Fig. 1. The interval is established by means of a cam and levers that periodically slide a pinion out of mesh with a gear reduction, thereby allowing the stylus to reset to zero, and immediately thereafter slide the pinion again into mesh with the gear reduction so that registration

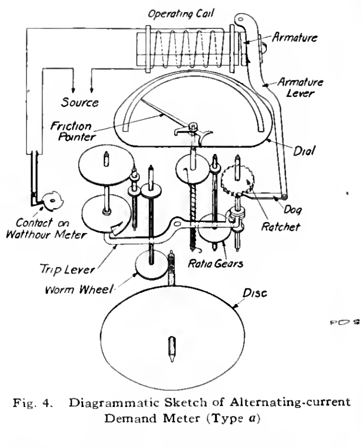


Fig. 4. Diagrammatic Sketch of Alternating-current Demand Meter (Type *a*)

may again take place. This mechanism gives a saw-toothed curve on the chart; and from the curve may very easily be determined the maximum demand, the time of the day, and the day of the week at which the demand occurred.

The demand meter listed in Class (*c*) is designed to print a record of the demand and the time of day upon a paper tape. It consists essentially of two elements: the registering element, and the recording or printing element.

The registering element is a solenoid fitted with a movable core or plunger. This plunger advances a set of cyclometer type wheels, each impulse of the solenoid advancing the "units" type wheel one unit.

The solenoid is energized by an electrical circuit, one side of which is controlled by a contact switch in the demand meter and a contact device installed on the register of the watthour meter with which the demand meter is used. The contact switch and the contact device are in effect three-way switches, the contact device being designed to close the circuit through the operating coil and the contact switch to open the circuit, thus preventing any possibility of over-

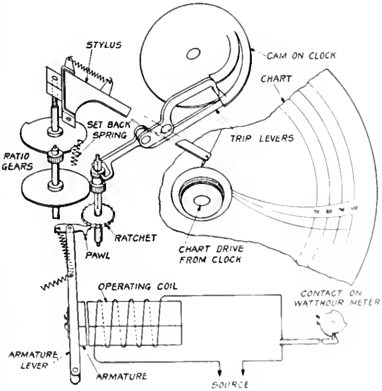


Fig. 5. Diagrammatic Sketch of Recording Demand Meter (Type *b*)

registration. It will be seen that the advance of the cyclometer or registering mechanism is at a rate depending upon the speed of the watthour meter with which the device is used, each advance of the "units" type wheel being a certain unit of demand.

The printing or recording mechanism is a solenoid fitted with a plunger, one end of which is provided with a printing platen and rubber pad. When the printing coil is energized, the plunger pushes the platen up against the type wheels of the registering

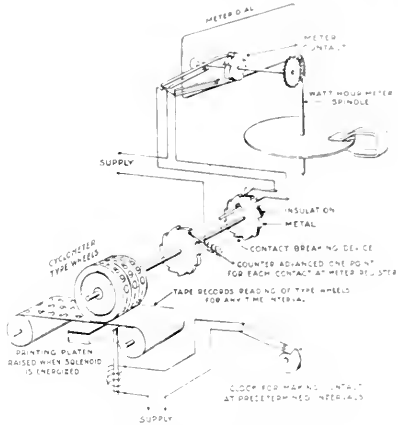


Fig. 6. Diagrammatic Sketch of Recording and Printing Demand Meter Type *c*

mechanism. This action of the platen prints a record on a paper tape which, together with a typewriter ribbon, is carried directly under the type wheels.

The action of the printing coil plunger also serves to advance the paper and type ribbons an amount sufficient to provide a blank space on the ribbon for the next record. Coincident with a printing of the demand record, a record of the time is also made. This record, however, is not printed in hours and minutes, but is printed in intervals per hour. For example, take a 15-minute device and the record between 9 and 10 o'clock a.m., the record of time would be the figure 9 printed four times for 9, 9.15, 9.30, and 9.45. Suitable provision is made for advancing the hour wheel at the proper time.

The printing mechanism of the device is actuated by contacts mounted on a clock. This clock is designed to close a set of contacts at stated and consecutive time intervals. the closing of these contacts [illegible]

It will be seen from the foregoing description that the various types of demand meters of General Electric manufacture are of the block-interval type, and embody some means or recording the contacts per interval made by a contact on a watthour meter and some means of establishing a definite time interval.

The general scheme of arrangement and operation is shown in the schematic diagrams, Figs. 4, 5, and 6. As has already been mentioned, these devices register the contacts as made by the contact devices installed in the watthour meters, and the time intervals, which are definite and consecutive, are established by some means such as a constant-speed inductive type of motor or spring-driven clock. It will be seen that by this method it is a very easy matter to obtain the kilowatts of demand by multiplying the readings obtained on the demand device by what is called a kilowatt constant result, giving demand in kilowatts per time interval.

This kilowatt constant, as it may be called, is derived from the following formula:

$$\text{Kilowatt constant} = \frac{W}{R \times N \times I}$$

where W equals the numerical value in kilowatt-hours of one complete revolution of the first pointer shaft of the watthour-meter register, R equals the register ratio, N equals the number of teeth on the contact cam, and I equals the time interval expressed in hours or fractions thereof. It may be well to explain that in obtaining the kilowatt demand from the device of Class (*c*) it is necessary to find the greatest difference between consecutive readings on the record roll or paper tape and multiply this difference by the kilowatt constant derived from the formula just given.

In equipping watthour meters with contacts it is the general practice to use a contact cam with such a number of teeth that the number of contacts per interval shall not be less than 70 nor more than 90. This will permit a 20 to 35 per cent over-load capacity on the meters shown in Figs. 1 and 3. Since the full-scale capacity of the dial in Fig. 1 and the chart in Fig. 3 is taken to be the 100-contact point, and both the dial and chart are provided with approximately six divisions above this 100-contact point, and since the number of contacts per interval is based on the full-load speed of the watthour meters upon which the contacts are to be mounted, approximately a 30-per-cent overload of the watthour meter is provided for.

Transmission of Light Through Water

By S. L. E. Rose

Illuminating Engineering Laboratory, General Electric Company

The subject of light transmission through different materials has been extensively investigated [illegible] scientists, physicists, and illuminating engineers. However, the author of the following article found no data on the transmission factor of light through water, and therefore carried out the investigation recorded below to obtain the lacking information. His investigation did not cover the surface losses due to light entering or emerging from water, as the apparatus used was not suitable for this purpose, but he intends to investigate this phase of the question at a later date.—Editor.

Though light is transmitted by vibrations in the ether, and ether permeates everything, it has always been a self-evident fact that the amount of visible light transmitted depends upon the transparency or opacity of the physical medium through which it passes. Within the scale of media ranging from vacuum at the one end, offering the least resistance to the passage of light, to the various opaque substances at the other end, offering infinite resistance, lie the relatively transparent and translucent materials. Of these intermediate materials the illuminating engineer is most concerned with air and glass, and in consequence he has thoroughly investigated their qualifications with respect to light transmission.

Occasion arose this spring to make illumination calculations involving the light transmission factor of water, but nowhere could such data on this medium be located. To secure the desired information an original investigation was made in the Illuminating Engineering Laboratory, the method of procedure and the data obtained being given in the remainder of this article.

Before prosecuting the investigation, two problems in performance had to be solved; the physical one that "in-water" photometric readings had to be obtained yet the photometer itself could not be immersed, and the mathematical one that some accurate reference base for the measurements had to be selected. The former was solved by immersing the photometer test plate horizontally just below the water surface; and the latter by arbitrarily selecting a virtual plane representing 100 per cent illumination at any given depth below the photometer test plate. As the measurements were made to determine a relative and not an absolute scale of light transmission, average values were obtained by repeating the calculations each time with a different standard plane since any plane of reference could be selected, as 100 per cent. between the photometer test plate and the light source.

The water container made use of in the investigation was a galvanized iron tank 14 inches in diameter, about $8\frac{1}{2}$ feet long, and open at one end. Inside was a carriage that could be moved along the axis of the tank. On this carriage was mounted the light source, a Mazda lamp with waterproof connections. Screens were provided to eliminate interior reflections. The tank was set upright on the floor and filled with Schenectady city water, which is clear artesian well water. As has been previously stated, the portable photometer was mounted

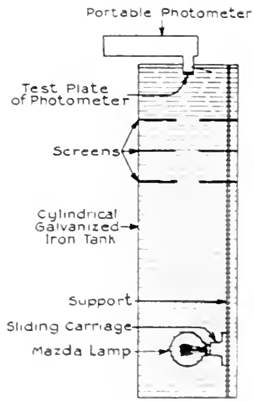


Fig. 1. Diagram showing Arrangement of Measuring Apparatus

at the top, so that its test plate projected below the water surface to eliminate any errors due to surface losses. A diagram of the arrangement is shown in Fig. 1.

Photometric readings were taken every six inches throughout the available range of

$5\frac{1}{2}$ feet of water. The use of any of the values obtained as 100 per cent permitted the transmission factor for one to five feet of water to be calculated without any error due to calibration.

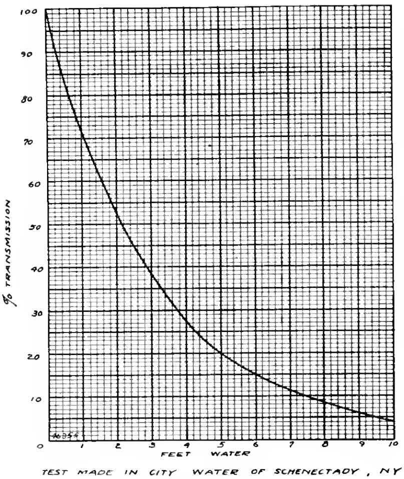


Fig. 2. Degree of Transmission of Light through Water

An analysis of the resulting data indicated that the measurements had been made with sufficient accuracy, and over a great enough range to make possible the calculation of the general equation for light transmission through water. This derived equation is as follows:

$I = I_o \times T^f$

I_o = initial intensity.

I = intensity after passing through f feet of water.

T = constant = transmission through one foot of water.

f = feet of water.

As an additional measure of accuracy, the formula was checked back against the test data and the results of this converse comparison were found to be well within the accuracy limits of the test method employed. Assurance was thereby obtained that the curve could be extended with reasonable accuracy beyond the limits of the test. Fig. 2 shows it extended to 10 feet of water and Table I gives the factors up to 100 feet, all being calculated from the derived formula.

Preparatory to making this investigation, it was the intention to examine the light transmitting properties of sea water as well as of fresh water, but difficulty in obtaining a good sample of sea water prohibited a test on this latter medium at the time. It is natural to suppose however that sea water, on account of its greater density, offers greater resistance to the transmission of light than does fresh water. The rapid decrease in the transmission factor with increased light travel in water coincides with the well-known facts that, for a so-called transparent medium, the ocean permits the penetration of daylight to but a surprisingly short distance below its surface and that fish native to the depths are blind or carry their own illuminants.

TABLE I

Feet of Water	Light Transmission Factors
1	0.725
2	0.526
3	0.381
4	0.276
5	0.200
10	0.040,1
20	0.001,61
30	0.000,064,6
40	0.000,002,59
50	0.000,000,104
60	0.000,000,004,17
70	0.000,000,000,167
80	0.000,000,000,006,72
90	0.000,000,000,000,269
100	0.000,000,000,000,010

Life in a Large Manufacturing Plant

PART X. CONTINUITY OF SERVICE

By CHAS. M. RIPLEY

PUBLICATION BUREAU, GENERAL ELECTRIC COMPANY

Against the background of the preceding chapters describing medical and safety work, restaurants, the apprentice courses and other schooling, and the various clubs and associations, this chapter, which is the last of the series, presents some provisions which specially tend to promote long service, such as supplementary compensation, vacations with pay, and the pension system.—EDITOR.

In his "History of Civilization" Buckle points out that the peoples of nations situated in extremely hot and in extremely cold climates are inferior to those in the temperate zone, because their continuity of employment is less. In hot countries steady work is impossible due to the extreme heat of the day, and in extremely cold climates steady work is impossible due both to the severity of the winter and to the diminished sunlight; for the "lands of the midnight sun" are, in winter, the lands of the noonday shade. Buckle states that the peoples of the temperate zone are less fickle, more energetic, and further advanced in all lines of human endeavor, because they work more continuously, i.e., with less breaks in their industry.

A business organization is very similar to a nation in that its strength and its characteristics are but the summation of the strength and characteristics of the individuals composing it.

Since steady work makes a nation great because its individuals become competent and expert, it would naturally follow that an industrial concern whose employees are steady workers, would be a stronger and better organization than if its personnel were largely composed of "floaters."

Lack of steady work weakens the character of the individual, and individuals of weak character find it difficult to obtain steady work; so it is apparent that there exists a vicious circle, and that the money losses are cumulative; moreover this money loss is mutual with employee and employer, inasmuch as both suffer through lack of steady productive work.

LONG SERVICE RECORDS

Let us visit the gatekeeper at the main entrance of the Schenectady Works and view the great army of industrial workers which pours out here at the end of the day. In less than three quarters of an hour most of the twenty-two thousand people leave the works—in round numbers an average of 500 per minute. How many of these are "old" employees?

250 are "5-year men," of whom
100 are "10-year men," and
15 are "25-year men"

Think what this means—four long-service men pass out every second, for the better part of an hour.

Remarkable Service Records at Schenectady

Fig. 1 shows the continuity of service of the Schenectady employees.

Half the individuals have been steadily employed five years or longer.

One out of every five has been employed ten years or longer.

One out of every thirty-four has been steadily employed twenty-five years or longer.

The details of these service records are:

No. of Employees	Years of Service
1	39
3	38 [illegible]
8	37
9	36
14	35
21	34
26	33
314	29
632	2[illegible]
660	2[illegible]
1,304	10
11,102	5

[illegible] curve, covering the period between 25 and 39 years of continuous service, was [illegible] from the records of the Quarter Century Club [illegible] Schenectady. The [illegible] Schenectady Quarter Century Club [illegible] 10,000 [illegible] years of service [illegible] would [illegible]

The five-year point was obtained from the records of those who receive the five per cent supplementary compensation, described later in the chapter. The ten-year point was obtained from the records of the factory employees on the wage basis who receive the one week's vacation with full pay after ten

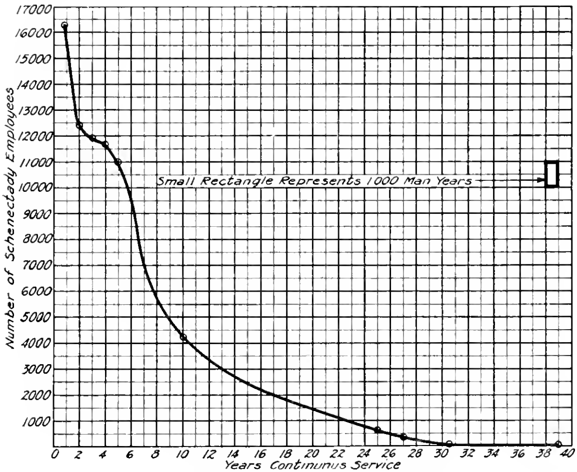


Fig. 1. Service Record, Schenectady Works

years of service, supplemented by the ten-year salaried employees in the General Office and Works.

The upper portion of this curve, showing how many employees have rendered less than five years of service was difficult to obtain, for it involved the inspection of 20,000 records one for each employee.

The figures from pay rolls five, ten and twenty-five years ago show that the number of five-year men now on the pay roll is 56½ per cent of the total pay roll five years ago. Similarly, neglecting transfer to and from Schenectady 39 per cent of those employed ten years ago remained on the pay roll July 1, 1918; and of the total of approximately 2600 employees at Schenectady twenty-five years ago, 660 or 25 per cent are still working in the Schenectady Works.

A Calculating Machine to Help

In a large manufacturing plant the clerical work of obtaining and studying full information regarding over 20,000 employees—their age, nationality, education, family relations, length of employment, number of times employed, the number who have left, their reasons for leaving, and a classification of the number that have left for different reasons is an exhaustive and a terrific undertaking. In order not to have an army of clerks to make and keep records of such facts, a statistical machine will be used in the Schenectady Works for obtaining such information as that given above for all of the employees, and for grouping them under many different headings.

The Hollerith machine, designed originally for the United States Bureau of Census in Washington, is used to compile classified lists of the country's population and for other similar purposes.

This machine, when applied to the question of labor supervision in a large factory, opens up a tremendous field of information which would be very difficult of exploration by usual methods.

A large factory should be able to segregate and classify such information according to headings which permit the management to draw adequate conclusions, make rapid diagnoses, and devise remedies to immediately meet new situations.

The classification of employees according to nationality, date, etc., is interesting from various standpoints. For instance, if it were desired to know how many British and Canadian citizens were engaged at the Schenectady Works subsequent to March 1918, cards are merely run through the machine and by an automatic electric selective process, presto! the information is at hand in the form of a stack of cards, and these cards are even counted electrically.

The statistics that are kept in connection with over 20,000 employees are almost unbelievable in amount to those who have not had actual experience in connection with such administrative matters.

The new system of statistical analysis in the employment department will soon be in operation, and there will be a punched card for each employee. On each card will be space for answering twenty-one different questions; six of these questions can have ten different answers each, and fifteen of these questions can have one hundred different answers each. Therefore, there are *spaces* for 1,560 different answers on each card. But in addition to the different answers there are thousands of combinations among these various answers; and when these thousands of combinations are taken in conjunction with 20,000 or more employees, it will be seen what a stupendous mass of statistics there are to be digested and intelligently classified and re-classified.

In a small or medium sized factory such information is not difficult to obtain and segregate, but in a plant of this size it is necessary to have the mechanical aid of this tabulating machine in order to promptly answer such questions as the following:

1. How many machinists were employed in the Turbine department in 1917 who were American citizens in the draft age, who had obtained a high school education? This question could be answered in three hours.

(2) How many persons were employed by the General Electric Company since August 1914, who are in the British draft age and subjects of Canada? This could be answered in two and one half hours.

(3) How many laborers were employed during the year 1917 who were illiterate, giving the percentages classified according to various nationalities? This could be answered in four hours.

(4) Classify the pay roll according to years of continuous service, i.e., How many employees have rendered continuous service for 3 years, 15 years, 24 years, and 32 years? This could be answered in one and one half hours.

(5) Classify the pay roll, showing how many employees are graduate apprentices, grammar school graduates, high school graduates, and how many are college graduates. This could be answered in six hours.

6. How many employees left during the year 1917 for each of the following reasons: military duty, sickness, dissatisfied with wages, disagreement with a fellow worker? This could be answered in two and one half hours. This question could demand twelve different classifications and still be answered in the same time required for the above four classifications.

The General Electric Company recognizes that steady work is of value to all concerned, and has instituted the following measures to promote and to reward those employees who have long records of continuous service:

Five Per Cent Supplementary Compensation

In addition to the ten-per-cent bonus of over five million dollars, paid to their employees in 1917, the General Electric Company distributed supplementary compensation in the year 1917 amounting to over $1,330,000 to employees who had rendered five years or more of continuous service up to that time. This supplementary compensation will continue to be paid until further notice to all employees who have rendered five years or more of continuous service. In 1917 this figure reached nearly 22,000 employees, including shop workers, clerks, engineers, commercial men, and office boys. This supplementary compensation is paid semi-annually and is equivalent to five per cent of the wage or salary during the preceding term.

The distribution of this supplementary compensation is shown in the following table which lists the different factories, and the number of employees in each who received this bonus:

Schenectady Works	11,102
Lynn "	4,364
Pittsfield "	1,938
Erie "	311
Ft. Wayne "	734
Edison Lamp Division	982
National " "	1,266

At the present writing the number of employees who are eligible to participate is increasing at every six-month period.

Vacations with Full Pay

No radical departures have been made in regard to the vacation granted salaried employees; but in the field of shop labor, a decidedly novel move has been inaugurated which has most interesting developments as possible or even probable in the future. Already the wage earners, or those on the daily or hourly basis in the shops, receive one week's vacation with pay after they have rendered ten years of continuous service. The following table will be of interest as it shows how many ten-year men are now employed in the shops on the wage basis:

Schenectady	3,300
Lynn	1,482
Pittsfield	250
Ft Wayne	192

The Pension System

All workers who have had twenty years' continuous service may be retired with a pension which continues until death. According to a strict interpretation of the pension rules, men must be retired at the age of 70, and women at the age of 60, unless special arrangements have been made with the pension board.

This pension is based upon his average annual wages for ten years prior to retirement, and also the total number of years of continuous service.

How the Pension Is Figured

After 33 years of continuous service, an employee's pension equals 49½ per cent of his annual earnings.

The exact formula for computing the pension is as follows:

The average annual wages for ten years prior to retirement, multiplied by the number of years in service, multiplied by 1½ per cent. For example, for one whose service has been continuous for thirty years and whose average earnings for the last ten years have been $2500 per annum, the annual pension upon retirement would be $1125; or figured per day, it would be $3.08 per day including Sundays and holidays. Such an employee, retiring at the age of 70 and living to the age of 80, would receive a total sum in pensions of $11,250 according to the schedule in force at the present time. The tendency at the present time is to increase the pension rate rather than decrease it, as is shown by the fact that the Board of Directors on March 20, 1918, authorized an increase of 50 per cent in the existing pension rate. The pensions are paid monthly by check.

Comparison of Pensions with Liberty Bond Income

Table, page 583, is prepared to show not only the annual pension received by employees who have rendered between 20 and 40 years of continuous service, but the last column shows also the capitalization of this pension.

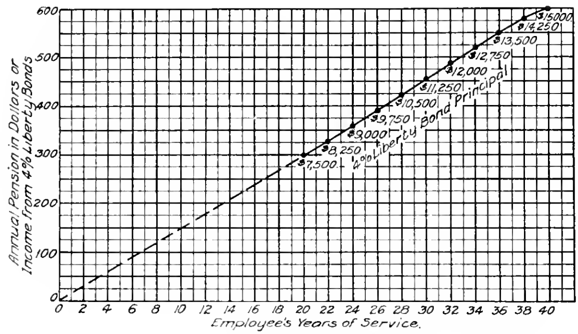


Fig. 2. Pension Rate per $1000 Average Wages for Various Periods of Service

For instance, a man who draws a pension of $300 per year until death, receives an income which is equivalent to that from $7500 in Liberty Bonds bearing 4 per cent interest; that is, his pension would be equal to his income if he owned $7500 of the 4 per cent Liberty Bonds. An employee rendering 40 years of service would for each $1,000 of annual earnings, receive $600 annually, or the equivalent of the income on $15,000 of 4 per cent Liberty Bonds. Obviously, if his earnings averaged $2000 for the last ten years he would receive twice that much, or $1200 per annum—the equivalent of the entire income of $30,000 worth of Liberty Bonds at 4 per cent interest. For the purpose of permitting rapid calculations, the following table and discussion are based on average annual earnings of $1,000 per year.

The curve, Fig. 2, shows graphically the pension received by retired employees according to different periods of continuous service between 20 and 40 years. The figures under the curves show the amount in Liberty Bonds which a man would have to possess in order that the income from them would equal his pension.

Number of Years	Annual Pension Until Death	Capitalization in 4 Per Cent Liberty Bonds
20	$300	$ 7,500
22	330	8,250
24	360	9,000
26	390	9,750
28	420	10,500
30	450	11,250
32	480	12,000
34	510	12,750
36	540	13,500
38	570	14,250
40	600	15 000

NOTE.—For retired employees whose earnings were more than $1,000 per year the pension and the capitalization are each increased proportionately.

An interesting and instructive feature of this diagram is the dotted section of the curve. It may be commented upon as follows:

An employee who has worked less than twenty years should appreciate that already a considerable sum of money has been set aside to provide for his pension, but that by resigning his position before the end of twenty years' service, he is forfeiting this asset which he has created by his continuous service. This asset for the $1,000 per year man with only a ten-year service, already amounts to the income from $3,750 Liberty Bonds for the rest of his life; and for the $2000 per year man amounts to $7,500 in Liberty Bonds; and both of these will be doubled when the full twenty-year record is complete. In other words, by continuing in his present position for ten years more he will be able to make secure this doubled asset; whereas by resigning from his position he throws away this much capital, the income from which he would begin to receive at the time of his retirement and which he would continue to receive until his death. Similarly those who have served a greater or lesser period can consult this curve to ascertain what has been set aside for them; but all should bear in mind that the figures are based on annual earnings of only $1,000 per year and should be increased proportionately for higher earnings.

What is "Continuous Service"

In connection with the pension system, the supplementary compensation plan and the 10-year factory service vacation, the expression "continuous service" is used. The rules governing the determination of each employee's service record are:

(1) Temporary absence and temporary lay-off on account of illness or because of reduction in force will not be considered as a break in the continuity of service, but when such absence exceeds six consecutive months it will be deducted in computing length of active service.

(2) If any employee, after leaving the service of the Company, shall be re-employed, he shall be considered as a new employee

(3) Leaving the service, as referred to in rule 2, is defined as follows:

(*a*) When an employee leaves voluntarily or is definitely discharged.

(*b*) When an employee absents himself from duty for two consecutive weeks or longer, without satisfactory explanation.

(*c*) When an employee, originally laid off because of reduction in force, fails to apply for re-employment within six months, or, being notified that he may return, fails to do so within two weeks of the date of such notice without satisfactory explanation.

(*d*) When an employee originally laid off because of illness fails to keep his department head informed monthly, or otherwise obtain approval of his absence.

(4) Leave of absence without pay may be granted individual employees, at the discretion of managers, but in every case it must be arranged in advance. If such absence exceeds three months it must be approved by the Supplementary Compensation Committee in advance, and the time, if it exceeds six months, shall be deducted in computing the net term of service.

(5) Leave of absence, without pay, for the purpose of securing a higher education and subsequently returning to active service in this Company, shall not be considered as a break in service provided arrangements are made in advance. If such absence is to exceed three months, it must be approved by the Supplementary Compensation Committee, and the time, if it exceeds six months, shall be deducted in computing the net term of service

(6) Military service, both State and National, is not necessarily a break in the continuity of service. If an employee enters any branch of military service, either as the result of draft or voluntarily with the consent of the Company, and at the date of enlistment he shall have been in the service of the Company six months or longer, the Company will, after his honorable discharge from the service in the Army or Navy, and if he applies for employment, endeavor to re-employ him whenever possible, either in his original position or in such other capacity as may be found practicable When again so employed after

military service, the employee's service with the Company for the purpose of computing pensions and other benefits, will be held to to have been continuous; i.e., his term of service with the Company will be inclusive of the time spent in military service.

(7) Supplementary compensation for five-year service shall be calculated only on the regular and overtime pay roll earnings for service actually performed, as will also the 10 per cent or any other bonus paid coincidently with regular wage or salary payments.

War Service, Casualties, and Honors in the Industry

The following article contains two reports, one from the British Thomson-Houston Company, and the other from the General Electric Company, the first representative of the war service of British electrical men, and the second representative of the war service of American electrical men.—Editor.

While newspaper accounts, magazine write-ups, motion-picture shows, etc., have kept us fairly well informed as to the prosecution of the war, they have given us but little information as to the number of men in service from the segregated industries of each of our European Allies. As we of the electrical fraternity are naturally most interested in the military service of electrical men, we take pleasure in presenting below a War Service, Casualty, and Honor tabulation recently received from the British Thomson-Houston Company and covering a four-year period. This information, which is dated April 4, 1918, gives us a better insight into both the glorious and the grim phases of the great war.

BRITISH THOMSON-HOUSTON COMPANY'S EMPLOYEES SERVING IN THE ARMY AND NAVY

Total number of employees who have enlisted	1,339
Died from all causes (13 per cent of number enlisted)	177
Wounded	160
Prisoners in Germany	5
Interned in Holland	1
Total casualties	343
Employees holding commissions	120
" given commissions from the ranks	86
" awarded the Military Cross	5
" awarded the Military Medal	20
" " " French Military Medal	1
" " " Serbian Gold Military Medal	1
Employees awarded the Belgian Croix de Guerre	1
" " " Distinguished Conduct Medal	9
who have been mentioned in dispatches	16
" who have been specially commended for service in the field	11

GENERAL ELECTRIC COMPANY'S EMPLOYEES

Last year the General Electric Review distributed with its November issue a Roll of Honor of the employees of the General Electric Company who had entered the military service of the United States. This edition of the Honor Roll gave considerable detailed information, but it is no longer up to date. We therefore present below a summary of as much information as can now be accurately reported regarding the war service which the employees of the General Electric Company have rendered to the Government in a little over one year.

Serving in the Army acd Navy

Number of employees in service, June 1, 1918	5,813
Died from all causes	12

Subscribing to Patriotic Funds

	No. Subscribers	Amount
First Liberty Loan	39,855	$3,002,850
Second " "	48,340	3,447,500
Third " "	55,251	4,126,950
Second Red Cross War Fund	60,625	504,8[illegible]

The Engineer's Opportunity*

By S. A. Redding

Superintendent Georgia Railway & Power Company

Mr. Redding holds the quite common view that the period immediately following the termination of the war will witness immense activity in all lines of industry in the rehabilitation of the world. Engineering knowledge will be in great demand and students of the subject foresee a wonderful opportunity ahead for the engineer, whether mechanical, electrical, or civil. The development of our water powers will receive first consideration, and it will be to the advantage of all engineers and engineering students to make a study of hydraulics in anticipation of this time.—Editor.

Judging from conditions as they exist in the world today, it requires only ordinary intelligence to comprehend in a general way what the future holds in store for the engineering profession, and particularly the younger engineers who are just starting out in business and have not fully made up their minds just what line of work to follow.

There never was a time in history when the engineer was in such demand as he is today, and will continue to be for many years to come.

When we stop to consider the enormous loss of life which has already occurred, and the additional loss which, unfortunately, is sure to follow; when we try to realize the almost inconceivable amount of property damage and destruction which has been wrought throughout Europe and on the high seas; and when we think of the enormous amounts of food stuffs, munitions, machinery, and supplies of all kinds that are absolutely necessary in carrying on a struggle of such magnitude, it can be readily understood why young men are destined to take such a conspicuous part in the affairs of the world in the near future.

The value of any commodity is based on the law of supply and demand, and with the supply limited and the demand practically unlimited, the values of commodities are bound to be high. This law applies equally well to manual labor and all other forms of human effort; this being true, think of the enormous amount of reconstruction which will have to be done—reconstruction of work representing many years of hard labor and fabulous sums of money—railroads, bridges, highways, industrial plants of all kinds, and even entire cities in the boundaries of which are included every kind of construction imaginable; then, on the other hand, consider the available supply of raw material, the limited manufacturing facilities, the shortage of man power—skilled mechanics and artisans of all kinds as well as common labor—and you will readily conclude that it will be difficult to overrate the importance of the engineering profession when peace finally comes.

Every branch of the engineering profession will be overrun with work, and while, from a purely money-making standpoint, there should be little to choose between the different branches, it is evident that one will most likely meet with the greatest measure of success by following the line of work in which he has the most decided talent.

The electrical and mechanical engineering fields will be very productive; the hydraulic and civil engineers will have their hands full; and the architect and textile engineer will also be in great demand.

From July 1914, when the War broke out, until we were finally forced to take a hand, the many electrical and mechanical manufacturing industries in the United States had been gradually changing over their existing plants and making new additions in order to take care of the requirements of the allies, but since our entry the requirements of our own Government have been so great and so urgent that practically every manufacturing concern in the country has been loaded beyond its capacity with Government orders of all kinds.

As a result of these emergency conditions, it is practically impossible for public utilities such as the telephone, electric light, power, street railway, and gas companies to secure promises of deliveries on equipment requirements in better than nine to twelve months except where it can be conclusively shown that the equipment or material required is to be used in actual Government production, and, on certain kinds of apparatus, quotations cannot be obtained at all. Furthermore, on account of the unsettled financial condition of the world since the War began, a great many of the public utility companies have been forced to steer close to shore in order to avoid financial disaster. The purchasing

*Abstract of an address to the student branch A.I.E.E. Georgia School of Technology.

of much needed equipment has been held off just as long as possible in the hope that the War would end in a short while; and so, when it does finally end, there is going to be a big commercial drive which will tax the capacity of the manufacturing forces to the limit.

Since many of the manufacturing concerns have had to change over equipment and plant arrangements in order properly to handle the Government war orders, it will be necessary for them to undergo a second transformation in order efficiently and promptly to meet the needs of the public utility companies, the steam and electric railroads, and the thousands of other industrial enterprises in the United States and neutral countries, in addition to the urgent needs of the devastated countries of Europe. One might well hazard the guess that depreciation and the wear and tear on railway lines and rolling stock, and on the machinery and equipment, running continuously day and night, during the past three and a half years, in feverish efforts to keep pace with the needs of war, will far exceed in money value the actual destruction caused by the war itself, great as this amount must be.

The serious coal shortage which was experienced last winter, while due to a combination of unusual circumstances, was a near national calamity which our Government will not allow to recur if possible. Certain phases of a similar situation in the future can, of course, be obviated by storing up coal during the summer months; but while such a precautionary measure would take care of domestic requirements, some other means will have to be devised to safeguard the cities and communities dependent upon the steam central-station and the gas plant for their electric light, power, and fuel for manufacturing as well as domestic needs.

The Government, as well as the central-station management and the manufacturer very clearly see the urgent necessity for immediate action to relieve the situation permanently.

The plan, which would be productive of the greatest relief in the shortest time, includes the general development of the numerous water-powers throughout the United States. The electric energy thus generated would be transmitted at high voltages to the cities, towns, and rural communities within a radius of 25 to 150 miles, the distance depending in large measure on the size of the development.

This plan of general water-power development, will, when put into effect, give great impetus to the movement already under way for a more general electrification of the great trunk lines all over the country. It is a well-known fact that the steam locomotive is one of the most uneconomical types of steam apparatus in use, consuming about six pounds of coal per horse-power-hour as compared with the modern steam turbine which consumes less than one third this amount.

In those sections of the country not favored with water powers, coal will continue to be the source of power; but it is quite probable that considerable attention and study will be given to the comparatively new practice of building the steam station at the mouth of the mine and transmitting the converted energy over high-tension lines to the centers of distribution, instead of hauling the equivalent amount of coal to the steam stations located in the cities and towns and other points remote from the mine. This scheme would release still more cars which would be available for the transportation of other commodities which, unlike coal, cannot be transformed and transmitted direct to their destinations. With the principal water-powers developed; with modern steam stations built at the mines throughout the country; with a large proportion of the trunk lines electrified; and with large government controlled coal depositories in every city throughout the country, filled during periods of light traffic, the solutions of the coal and transportation problems will be found.

Now, what has been said applies not only to our own country and the allies, but to practically every neutral country throughout the world; for while no single nation at war has supplied all the manufactured exports to all of these neutral countries, all of the belligerents together have, in the past, supplied practically all of the machinery and manufactured goods of all kinds, used by all of these neutrals. Surely, if we, right here in the heart of the industrial world, have been unable to secure much needed equipment, it does not stand to reason that the neutral countries have been able to do so. The probabilities are that they are as bad if not worse off than we are, so when the great struggle is over, Brazil, Argentina, Chile, Peru, Bolivia, and the smaller republics of South and Central America, and Spain, the only country of any size in Europe not participating in the war, will be pleading, along with the rest of the world, for machinery of all kinds and the engineers and skilled mechanics to make the installations.

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FLOODLIGHTING OF THE WASHINGTON SQUARE ARCH NEW YORK CITY ON THE OCCASION OF THE VISIT OF THE FRENCH AND BRITISH COMMISSIONS

Illustrating the article [illegible]

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE — Editor, JOHN R. HEWETT — Associate Editor, B. M. EOFF — Assistant Editor, E. C. SANDERS

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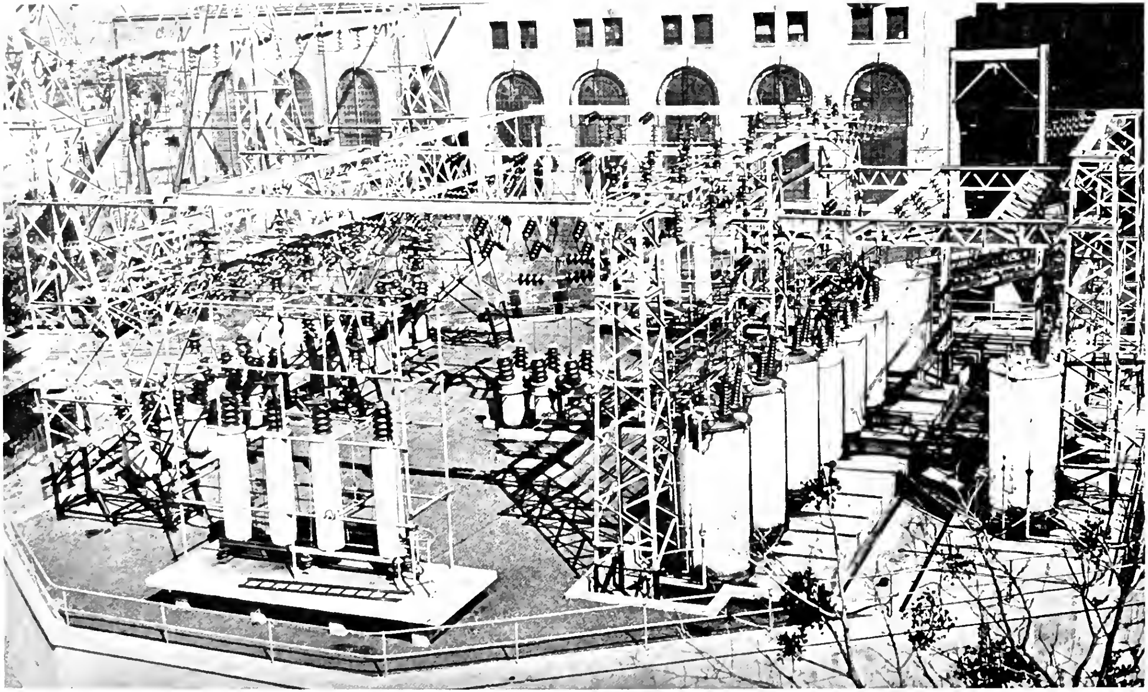


Partial view of a typical large size outdoor substation (60,000 volts high tension, 2400 volts low tension) including outdoor power transformers, oil circuit breakers, lightning arresters, disconnecting devices, and bus structure. Outdoor substations are equipped with apparatus successfully operative under any climatic conditions and can be built in any capacity. (See page 640.)

GENERAL ELECTRIC REVIEW

THE OXIDE FILM LIGHTNING ARRESTER

The oxide film lightning arrester, which marks another important step in lightning protection, was first described by Dr. Steinmetz and Captain Crosby Field in two separate papers at the Atlantic City convention of the A.I.E.E. As pointed out in these papers, which we are publishing in this issue, the aluminum arrester has been universally used where the best protection was desired; but it possesses some features which prove inconvenient at times and make its use impractical in some cases. The principal one is the need for daily charging by connection to the line, which is necessary to keep the dielectric film in good condition. Therefore the need of an arrester similar to the aluminum arrester in protective value, but one which would require practically no attention and which could be extensively used in isolated locations, has been obvious.

The oxide film lightning arrester is the result of development work begun with the idea of overcoming this necessity for daily charging. Although the oxide film arrester is in no way a form of the aluminum arrester, its characteristics and protective features are very similar. While the action of the aluminum arrester is electrolytic, that of the *O-F* arrester is principally thermal, depending upon the fact that the common chemical lead peroxide, PbO_2, has comparatively a very low electrical resistance and is very unstable when subjected to a temperature of about 250 deg. C, changing instantly into a lower oxide having the properties of an insulator. The three characteristics—low resistivity, quick reduction at about 250 deg. C., and extremely high resistance of the lower oxide—are peculiar to lead peroxide.

Any metal, it appears, can be used for the electrodes, and a great variety of insulating films are available. As the lead peroxide filler is a dry powder, the whole cell is simple, sturdy, and compact. Each cell is complete in itself and is shipped ready for use, which is, of course, not the case with the aluminum arrester. As the theory of the action of the aluminum and *O-F* arresters is totally different, it is surprising that their operating characteristics should be so nearly alike. Oscillograph studies show them to be virtually identical under practically all kinds of discharge.

Tests under actual operation, extending over about three years, have been made with the *O-F* arrester. In obtaining data from these tests, use was made of the coherer discharge alarm recorder, described by Mr. C. E. Green in our issue of July 1917. This device gives an accurate record of the discharges of a lightning arrester, and is of particular value when studying the protective properties of a new type of arrester. Because a lightning arrester has been in circuit a year or two and no apparatus has been lost, is not at all a positive indication that the arrester is efficient; it may well happen there were no serious disturbances. If, however, a recording device shows many discharges, conclusions are much more definite. About sixty *O-F* arresters ranging in voltage from 11,000 to 38,000 are now installed on commercial circuits, and the results have been very satisfactory.

Although applicable for practically any circuit conditions, it would seem that the principal field for this arrester is in localities where daily attention is impractical or impossible, but where efficient protection is desired. During the last few years the number of isolated stations has increased tremendously, and the class of service they supply warrant maximum protection. Till now it has been necessary either to go to the expense of providing daily attention for arrester charging alone, or to go without protection. Present conditions make it imperative that all unnecessary work, such as these special trips to charge arresters, be eliminated, and that electric power service be uninterrupted.

The Oxide Film Lightning Arrester

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

In this article and the following one by Mr. Crosby Field is described a new type of lightning arrester. Dr. Steinmetz gives a short history of lightning protection of electric systems, ranging from the early communication circuits to the present high tension, high capacity transmission lines, employing for lightning protection small air gaps and the aluminum cell lightning arrester, respectively. The advantage of the oxide film arrester lies in the fact that it does not require daily charging, as is the case with the aluminum cell arrester. Oscillograph records of tests on the oxide film arrester are shown and discussed, and a short description of the construction of this arrester and its principle of operation is given.—Editor.

Three periods can be distinguished in the development of lightning arresters, corresponding to the three periods of the use of electricity:

(1) Electric circuits of negligible power, telegraph, and telephone.

(2) Electric power circuits of negligible electrostatic capacity; d-c. lightning and railway, a-c. secondary and 2300-volt primary distribution.

(3) High-voltage electric power circuits, transmission lines, etc.

(1) In electric circuits of negligible power such as telegraph and telephone circuits, a simple minute spark gap to ground afforded protection by discharging lightning to ground, and was sufficient until the recent years, when with the general introduction of electric power circuits the problem arose in electric communication circuits to take care of crosses with power circuits.

(2) In electric power circuits, a simple spark gap to ground became insufficient for protection, since the power current, following the lightning discharge as arc, short-circuited the system and burned up the arrester. The problem then arose to safely open the short circuit of the machine current to ground, through the lightning arrester, after the lightning discharge has passed, and to leave the arrester in operative condition to receive following lightning discharges.

Of the various devices developed heretofore, the magnetic blow-out lightning arrester still is used in direct-current railway circuits.

The first scientific investigation of this problem is recorded in the paper * by A. J. Wurts, presented before the A.I.E.E. at the meeting of May 1894. Since that time all lightning arresters for alternating-current power circuits of negligible electrostatic capacity are based on the multigap principle between non-arcing metals, whatever constructive forms the arrester may assume—as the present compression chamber lightning arrester. The multigap arrester operates on the principle that the lightning discharge over the multigaps closes the circuit to ground, but the power arc following the discharge extinguishes at the end of the half wave of the alternating current, as the non-arcing character of the gaps does not permit the reverse current of the next half wave to start. The multigap arrester thus short-circuits for a part of a half wave. It obviously is suited only for alternating currents.

For years difficulties were met with the question of resistance; without series resistance, in large systems the short-circuit power even of a part of a half wave may be sufficient to disable and destroy the arrester, while the use of a series resistance, while limiting the power current and thereby protecting the arrester, also limited the discharge capacity and thereby reduced the protection. This problem was solved by the use of multigaps shunting the series resistance, so that moderate discharges passed over the resistance, while high power lightning discharges found a path without series resistance over the shunted gaps, and at the same time the shunting resistance made the power arc at the shunted gaps unstable, and thus assisted in the extinction of the short circuit at the end of the half wave.†

(3) As soon, however, as circuits came into use, which had considerable electrostatic capacity, such as high-voltage transmission circuits, extended underground cable systems, or lower voltage circuits (including generator circuits) inductively connected with such circuits, the multigap arrester failed by frequently, or even usually destroying itself by the discharge, burning up.

In such circuits, oscillations between capacity and inductance may occur, started by a lightning discharge or any internal disturbance such as switching etc., resulting in

* Trans. A.I.E.E., 1894, vol. xi, p. 337, "Discriminating Lightning Arresters and Recent Progress in Means for Protection Against Lightning," by A. J. Wurts.

† See A.I.E.E. Trans., 1907, vol. xxvi, p. 425, "Protection Against Lightning, and the Multigap Lightning Arrester," by D. B. Rushmore and D. Dubois.

recurrent high frequency oscillations, of which the arcing ground on a transmission line is typical, and probably best known. With such continual discharges, often several per half wave, the multigap arrester short-circuits at the first oscillation, for the remainder of the half wave, and while the multigap functions properly and opens the short circuit at the end of the half wave, the oscillation of the next half wave again short-circuits, and so on, so that the effect is that of a continuous short circuit, and no lightning arrester, no matter how large, can dissipate the short-circuit power of a big system for any appreciable time.

For such systems, in which recurrent high frequency oscillations, as arcing grounds, may occur, a lightning arrester is necessary which does not short-circuit the machine current even for a fraction of a half wave, but merely discharges the over voltage, the oscillation which, however high in voltage it may be, is small in energy compared with the short-circuit power of the system, as it represents only the stored energy of capacity and inductance. The only arrester of this character heretofore was the electrolytic, or aluminum cell lightning arrester, developed by E. E. F. Creighton, J. L. R. Hayden, F. W. Peek, and others. It acts towards an over-voltage discharge like a counter e.m.f. equal to the normal circuit voltage, and the discharge current passing through the arrester thus is the short-circuit current of the over voltage, while the normal machine voltage does not discharge, is held back and not disturbed. The aluminum cell arrester thus can discharge continual disturbances, over-voltage oscillations occurring at every half wave, for a considerable time, half an hour to several hours, before it is endangered by the temperature rise due to the accumulated energy of these discharges.

The aluminum cell arrester comprises a series of cells—usually conical and stacked into each other—of aluminum electrodes with an electrolyte, of which neither the salt nor its ions appreciably dissolve alumina. In "forming" the cell, by an alternating current passing through it, the electrodes are coated by a thin non-conducting film of alumina which grows in thickness until it holds back the impressed voltage. Any over-voltage punctures this film, but the current passing through the puncture holes again forms alumina and closes the holes. Thus the aluminum cell acts like a self-repairing electrostatic condenser of a disruptive strength equal to the impressed voltage: about 250 to 300 volts per cell.

The practical experience of the last ten years has proven the aluminum cell arrester as the only type capable of affording protection in modern high power circuits, and proven this so conclusively as to lead to its universal adoption in such circuits in spite of the inconveniences incident to the need of daily attention in charging, the use of a liquid electrolyte, and the difficulty of testing the arrester without taking it apart, except by watching the appearance of the charging arc or measuring the charging current.

These inconveniences incident to the aluminum cell arrester were well realized however, and as soon as the minor troubles met with the aluminum cell arrester in the early years had been overcome, engineers went energetically to work on the problem of developing a lightning arrester of the characteristics of the aluminum cell arrester, but which does not require any attention beyond that given to every apparatus in a well-managed system, that is, an occasional inspection, at least once or twice a year.

*The *Oxide Film Lightning Arrester* represents a new type of lightning arrester which has all the characteristics and advantages of the aluminum cell arrester but does not require any charging and thus requires no special attention, contains no liquid electrolyte, no inflammable material, and like the aluminum cell arrester can be located outdoors as well as indoors.

The oxide film arrester, like the aluminum arrester, acts like a counter e.m.f. equal to the normal circuit voltage, freely discharging any over voltage, but holds back the normal machine voltage. Thus the discharge is limited to the energy of the over voltage, as in the aluminum arrester, and like the latter the oxide film arrester can continuously discharge recurrent surges such as arcing grounds, etc., without endangering itself for a considerable time, sufficiently long to notice and eliminate the disturbance.

Compared with the almost entire absence of knowledge of lightning phenomena in electric circuits, under which Mr. Wurts had to work in developing the non-arcing metal multigap lightning arrester, our present knowledge of lightning phenomena is very great. Nevertheless, there are so many

* In the development of the oxide film arrester many researches were made by the engineers whose splendid work I here acknowledge: Messrs. H. D. Brown, V. E. Goodwin, J. L. R. Hayden, and G. B. Phillips; and more particularly E. E. F. Creighton, Crosby Field, and N. A. Lougee.

disturbances in large electric systems which we cannot or only incompletely reproduce in our laboratories, that the final decision on the success, that is, the effectiveness and permanence of a lightning arrester still is best given by the experience in industrial systems.

Therefore, after extensive laboratory tests had been completed and had proven the oxide film arrester as of the same characteristic as the aluminum arrester, but requiring no special attention, a number of industrial installations were made, and more added the next year and the third year. Now, however, when a considerable number of installations of these arresters, for voltages from 110 to 33,000 have been in successful operation, some for over three years, and have proven their protective value and their permanence, I consider it desirable to bring the arrester to your attention.

Of the numerous tests made on the performance of the arrester, it may be sufficient here to give only two by the oscillograms, Figs. 1 to 4, showing the action on a recurrent oscillation in Figs. 1 and 2, and on a single high power impulse Figs. 3 and 4.

The tests, oscillograms Figs. 1 and 2, were made in the usual manner: a surge or continual oscillation was produced by a large condenser connected to an alternating-current supply, and discharging over a spark gap through an inductance. The latter was chosen so as to give a frequency of 1200 cycles to the oscillation, and thereby bring it well within the range of the oscillograph. This surge was impressed upon the apparatus to be protected, a transformer energized by another alternating-current circuit. Fig. 1 shows the oscillogram without protection of the transformer, and Fig. 2 the oscillogram with an oxide film cell shunting the transformer and thereby protecting it.

In Fig. 1, the lowest curve shows the voltage

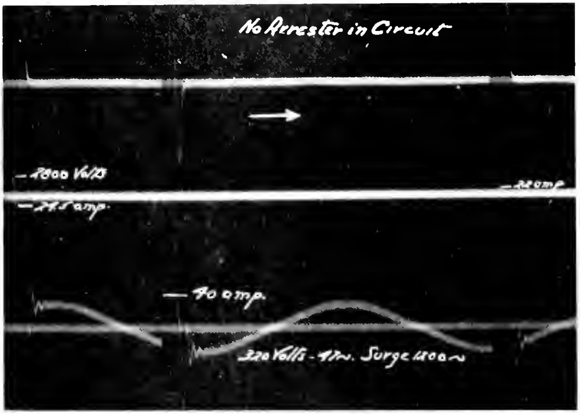


Fig. 1. Oscillogram of a Surge Discharge as in Fig. 2 with no Arrester in Circuit

Top vibrator—current through transformer
Bottom vibrator—circuit voltage

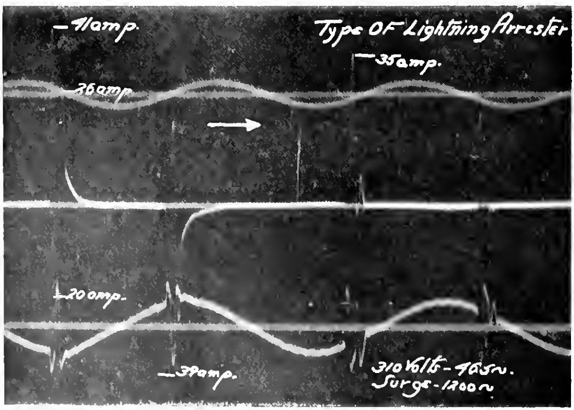


Fig. 2. Surge Discharge through Arrester Cell

Top vibrator—60-cycle timing wave
Middle vibrator—current through arrester
Bottom vibrator—voltage across arrester

of the 320-volt, 47-cycle power supply circuit of the transformer, with the oscillations superimposed on it, rising to surge peaks of 2800 volts. The upper curve shows the oscillating currents passing through the transformer, rising to current peaks of 40 amperes. The middle curve is absent as no arrester is used in this test. In Fig. 2 however, where an oxide film cell is shunted across the transformer, the middle oscillogram shows the current oscillations passing through the arrester, with peaks of 35 to 41 amperes. The lower curve in Fig. 2 then shows again the circuit voltage wave impressed upon the transformer, with the oscillations cut down by the oxide film cell. This voltage wave, the lower curve in oscillogram Fig. 2, well illustrates the characteristic action of this type of "counter-e.m.f. arrester"—to which the oxide film arrester and the aluminum cell belong. The oscillation peaks are sharply cut off at a maximum voltage of 60 per cent above circuit voltage, the value for which the spark gap was set. As the result, the oscillations are very greatly cut down from the high values which they have in the unprotected circuit Fig. 1 (2800 volts), and become unsymmetrical. The half waves of oscillation in the same direction as the circuit voltage are greatly reduced by the limitation of the voltage to 60 per cent above normal, while the reverse half waves—which lower the instantaneous circuit voltage—are less affected. Corresponding thereto the discharge current through the arrester, the middle oscillogram in Fig. 2, is unsymmetrical also; in the first and second oscillation of Fig. 2, the first and third half wave of oscillating voltage is cut off, and the first and third half wave of the oscillating discharge current therefore higher than the second half wave of the oscillating discharge, which latter corresponds to a half wave of oscillating voltage in opposition to the circuit voltage.

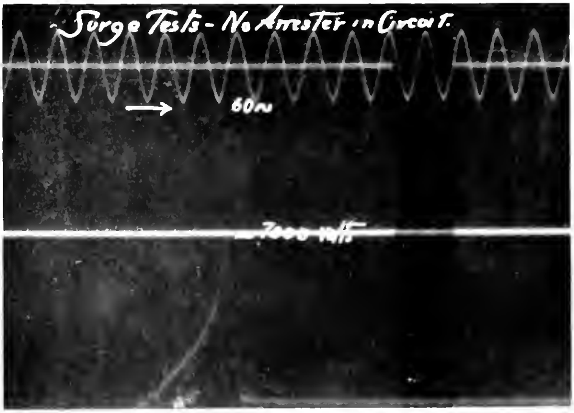


Fig. 3. Single Impulse Discharge with no Arrester in Circuit

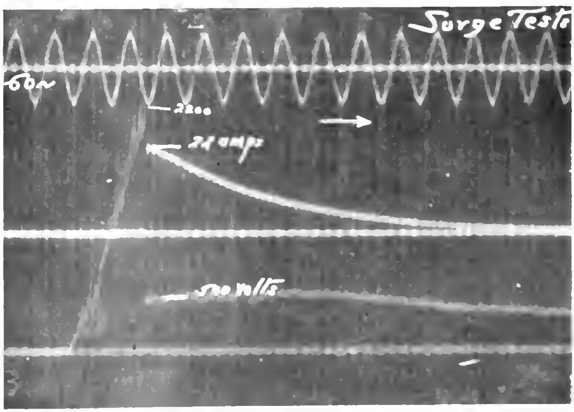


Fig. 4. Single Impulse [illegible] Circuit

therefore not raising the circuit voltage. The third oscillation of Fig. 2 happens to start with a half wave of oscillating voltage in opposition to the circuit voltage, and the first half wave oscillating discharge current through the arrester, in the middle curve,

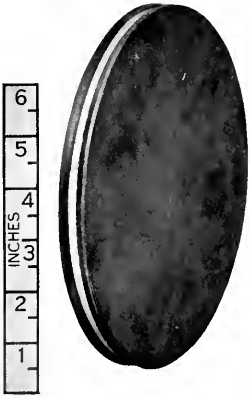


Fig. 5. Oxide-film Lightning Arrester Cell

thus is smaller than the second half wave; the second half wave of the oscillation is cut down in the voltage and therefore gives the maximum discharge current, 35 amperes in this case.

This feature is well brought out by the oscillograms Figs. 1 and 2, due to the use of a different frequency, 60 cycles, for the power supplying the oscillator. This caused the successive oscillations to occur at different parts of the half waves on the 47-cycle circuit which was to be protected.

Figs. 3 and 4 then show the protective action of the oxide film arrester on a 550-volt, direct-current circuit, against a single (non-oscillatory) impulse produced by opening a highly inductive circuit (railway motor). Fig. 3 shows on the lower curve the oscillogram of the impulse in the 550-volt circuit, rising to 7000 volts. The upper curve merely is a 60-cycle timing wave, to enable measuring the duration of the impulse. Fig. 4 shows the same circuit, with an arrester shunting it. The impulse voltage rises to the value for which the discharge gap of the arrester is set, in this case 2200 volts. Then the arrester discharges, and the voltage instantly drops back to normal, while a slowly decreasing discharge current through the arrester dissipates the magnetic energy of the impulse.

The cell of the oxide film arrester, shown in Fig. 5, consists of two circular metal plates as electrodes, which are kept apart by a porcelain ring, as shown in the figure. The space between the electrodes inside of the porcelain ring is filled with the active material, lead peroxide PbO_2, which is put in under moderate pressure. This active material is a good conductor, but has the characteristic that by the action of an electric discharge it is converted in the path of the discharge into a lower oxide, which is an insulator. Thus when an alternating current is passed through such a cell, the active material at the electrodes gradually converts into a non-conductor, and forms a thin insulating film at the electrode. This grows in thickness until it cuts off the further flow of current and holds back the voltage, about 250 to 300 volts per cell. Then only a small leakage current, of a few milliamperes, passes at normal voltage, but if an over voltage of any kind appears at the cell, the insulating film of lead oxide punctures and freely discharges through the lead peroxide, but in doing so converts the surface of the lead peroxide in the path of the discharge into the lower non-conducting oxide, and thereby closes the puncture holes, repairs or reseals the film.

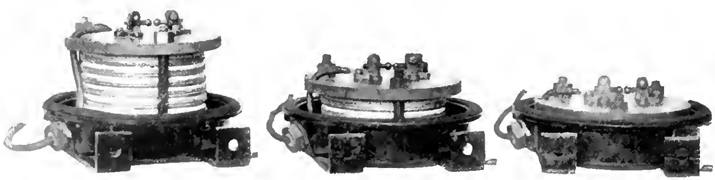


Fig. 6. Oxide-film Lightning Arresters with Covers Removed. Ratings 325–650, 900–1350, 2100–2600-volt Alternating Current or Direct Current Respectively

In manufacture, naturally, just as in the aluminum cell arrester the insulating film is not produced after assembly of the cell by the slow process of passing a current through, but the film is put on before assembly, in the oxide film arrester, by dipping the plates in a suitable insulating varnish which gives them a coating just thick enough to hold back the circuit voltage. Then after assembly, voltage is put on the cell for testing it and sealing any holes or defects which may exist in the varnish film.

In the oxide film arrester, the electrodes have nothing to do with the arrester action, and any suitable material can be used. First we used brass, but now use sherardized iron, the latter having a higher melting point and thus standing high power discharges, which would melt holes in the brass electrodes.

In this arrester, the action, which holds back the normal voltage but passes freely an over voltage, thus resides in the active material between the electrodes, and it is this material which forms and reforms the film. As this material is a solid, no chemical action occurs such as the gradual dissolution of the alumina film in the aluminum cell arrester, but the film remains intact permanently, and thus no daily "charging," that is, repairing of the film is required.

A number of such cells, depending on the voltage of the circuit, are piled on top of each other, with a spark gap in series, and, for low and moderate voltages, incased as shown in Fig. 6.

As the cells are hermetically sealed, by the metal of the electrodes being spun over the porcelain separating ring, the cells can be installed outdoors as well as indoors, requiring in outdoor installation merely some protection by petticoats, as shown in Fig. 7, to keep the rain from short-circuiting the cells. Fig. 8 shows such an outdoor installation of a 33-kv. arrester, with three-phase stacks and the ground stack of cells, protected against the weather by metal petticoats. Fig. 8 shows also the spark gaps on the line side of the arresters. They are protected sphere gaps, to give instantaneous discharge, with a horn attachment to allow the arc to flare up and thereby help in its extinction.

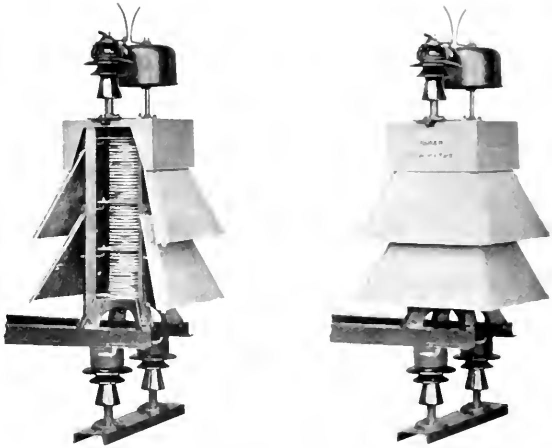


Fig. 7. Phase Section of 15,000 25,000-volt Outdoor Oxide film Lightning Arrester with side of housing removed to show interior arrangement

As well known, the plain horn gap has the disadvantage of requiring an appreciable (though a very short: microseconds) time for discharge, and an extremely sudden high voltage, as a very steep wave front, thus may pass the horn gap and flash over elsewhere. Therefore in modern high voltage lightning arresters the horn gap is shunted by a properly proportioned sphere gap, the latter being "instantaneous" in its action. In outdoor use, however, rain lowers the discharge voltage of the sphere gap, and thus requires a setting which gives a higher discharge voltage in dry weather than necessary. Therefore a protected sphere gap has been designed which overcomes this disadvantage in the open sphere gap, and is shown in Fig. 8.

The need of using this spark gap in series with the arrester is the only still remaining undesirable feature which the oxide film arrester shares with the aluminum cell arrester, the multigap arrester, and other types. While by the work of Mr. F. W. Peek on the time lag of electric discharges*

* A.I.E.E. Trans. 1915, vol. xxxiv, Part II, [illegible] Effect of Transient Voltages on Dielectrics," by F. W. Peek.

the means have been given to make the discharge gap "instantaneous," that is, faster than any other discharge path over gaps

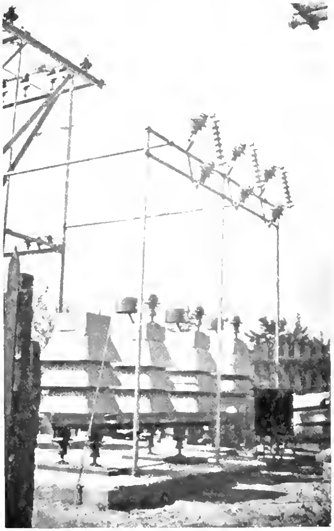


Fig. 8. Oxide-film Lightning Arrester for Outdoor Service Installed on a 33,000-volt Circuit

or through insulation in the system, so that the arrester takes care effectively of any over voltage above its discharge voltage; it does not discharge voltages lower than the discharge voltage of its spark gap, even if these lower voltages may involve some danger to the system by their high frequency. Such low voltages, while they cannot endanger the main insulation between circuit and ground, may, if of sufficiently high frequency, lead to local accumulations of voltage across inductive parts of the circuit, as regulators, current transformers, end turns and coils of generators and transformers, and there cause damage by puncturing insulation between turns and causing internal short circuits.

Against these high frequency disturbances of moderate voltage, the only existing protection is the addition to the arrester of a capacity discharge path permanently connected from the circuit to ground. Such capacity path should be without resistance to flatten steep wave fronts, and contain a moderate series resistance, to dissipate high frequency energy and stop cumulative oscillations in their beginning. Before I leave the field of electrical engineering, I hope still to see an arrester, of the type of the oxide film or the aluminum cell, which has no spark gap, but is permanently shunted across the circuit, and thus capable of taking care not only of over voltages, but equally well of steep wave fronts and high frequency oscillations, even if of lower than the circuit voltage. Such an arrester then would give universal protection.

The Oxide Film Lightning Arrester

By Crosby Field

This paper is mainly a description of the principle and construction of the oxide film lightning arrester. It consists fundamentally of an insulating film placed between a conductor (usually metallic) and the conducting powder, lead peroxide. When subjected to over-voltage this insulation will be pierced, but the heat of the discharge will rapidly convert the lead peroxide into an insulating plug and stop the discharge. As we have previously mentioned in several places, the advantage of this arrester over the aluminum cell arrester lies in the fact that, while it affords the same high degree of protection, it does not require daily charging as does the aluminum arrester, and can be installed in a great many places where the need of daily charging by the aluminum arrester would preclude its use.—Editor.

This paper will be confined to a brief statement of the scientific principles underlying a new type of lightning arrester called the "oxide film arrester."* The functioning of this arrester depends upon the fact that certain dry chemical compounds can be changed with extreme rapidity from very good conductors of electricity to almost perfect nonconductors by the application of a slight degree of heat. Lead peroxide is a good example of such a substance. It has a specific resistance of the order of one ohm per inch cube. The resistance varies with the pressure to which it has been compressed. At a temperature of about 150 deg. C. the lead peroxide (PbO_2) will be reduced to red lead, commercially known as minimum (Pb_3O_4). This has a specific resistance of about 24 million ohms per inch cube. At slightly higher temperatures this minimum will be reduced through the sesquioxide (Pb_2O_3) to litharge (PbO), which last named is practically an insulator. [A megger reading of infinity is obtained on a column 3 millimeters long (0.11 in.) and 5 square millimeters area (0.2 sq. in.).]

Again the oxides of bismuth give similar characteristics. There are, furthermore, several other compounds and mixtures of compounds that will give these same results.

Lead peroxide is normally in the physical state of a powder. If this powder be placed between two electrodes and a current passed, the temperature due to the resistance at the contact of the peroxide and the metal will cause heat to be generated locally at the surface. When this heat is sufficient to create a temperature of about 150 deg. C. a film of the lower oxides of lead forms, producing a film of insulation which stops the current. This method of film formation over any large area is rather irregular, and of course the oxide is not used in such a fashion in the commercial arrester. Instead of this formation of litharge film any insulating film may be put on the electrodes initially. As insulating film spread on the metal plates there have been used thin layers of the following: glass, water glass, halowax, cloth, balsam, shellac, oil, paints, lead paints, varnishes, and lacquers of all available kinds. In all cases the results are similar, varying only with the voltage at which puncture of the film of insulation occurs.

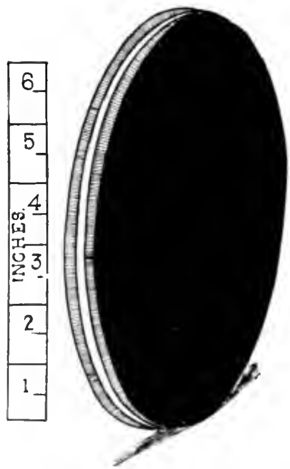


Fig. 1 A Single Cell of the Oxide Film Lightning Arrester consisting of a ring of porcelain with two circular steel disks, one spun on each side of the porcelain and insulated by the porcelain. The inside of the ring of porcelain between the plates is filled with peroxide of lead.

The foregoing statements define the principle of the commercial oxide film arrester, Fig. 1. It comprises two steel metal electrodes, set about 0.5 in. (12.7 mm.) apart, one or both covered with a thin insulating film and the space between the plates filled with some such substance as that described

* U.S. Patent No. 1,238,660—Crosby Field.

above, as, for example, lead peroxide. Fig. 2 shows the disassembled parts of a single cell. At a permissible voltage of 300 volts per cell the insulating film prevents any appreciable current flowing under normal conditions. As soon as the voltage rises slightly above normal the film punctures in one or more microscopic points, the lightning charge meets with practically no resistance and flows to earth, Fig. 3. The dynamic current starts to follow but because of the fact that the insulation was punctured in such fine points, the current density near these points is exceedingly great. This results in a localized heating which speedily raises the temperature to a value sufficient to change to insulating litharge all the conducting peroxide in this minute path of the current flow in contact with the electrodes. The film consequently reseals, stopping the further flow of dynamic current. This action is so rapid that its duration cannot be measured on an oscillograph giving two thousand cycles per second, that is to say, the action of resealing occurs in less than one four-thousandth part of a second after the excess of lightning voltage has ceased. These spots of insulating litharge plugs are visible on the surface of an electrode.

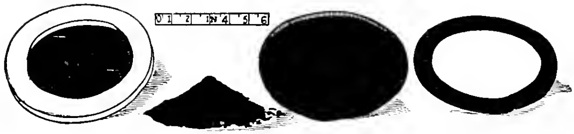


Fig. 2. Shows the Disassembled Parts of a Single Cell of the Oxide Film Lightning Arrester. From left to right are a steel disk spun on a ring of porcelain, a pile of brown peroxide of lead, the other steel disk, and an asbestos washer.

This film can be made of litharge itself, as well as any of the insulating materials above named. For example, metal plates may be inserted in any of the well-known lead electroplating solutions, and thus a very thin lead peroxide film (measuring a few hundred thousandths of an inch) formed. By proper heating this will be changed to litharge and this form of electrode can be used. Peroxide may also be sprinkled over any metal plate and the plate heated, which will reduce the peroxide to litharge. Again, the metal chosen for the electrode itself may be lead, and if heated in the air a thin film of litharge will be formed on the surface. Again, an aluminum electrode may be put in any of the common electrolytes, and a thin aluminum film be built up. This may be used with the peroxide powder. Of these methods of forming the film the most preferable is by dipping in varnish or lacquer highly burnished surfaces of brass, steel, or copper, and is consequently used in the commercial arrester. The ohmic resistance of the arrester during discharge is quite low (less than 1 ohm per cell). Thus, when the insulating film is punctured the arrester offers very slight impedance to the flow of energy at abnormal voltages.

There is a certain range of voltage necessary to pierce any given insulation. The exact

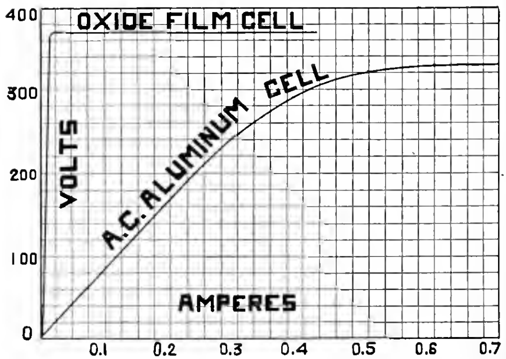


Fig. 3. The Comparative Volt-ampere Characteristics of the Oxide Film Cell and the A-c. Aluminum Arrester Cell. The oxide film has only a few milliamperes of leakage current up to the critical film voltage when the film gives way more suddenly than the film in the aluminum cell. The critical voltage of the oxide film can be made approximately as low as the hydroxide film on the aluminum cell.

voltage depends not only upon the thickness of the insulation and its dielectric strength, but also on the relation of the dielectric spark lag to the duration of the super-spark potential and the frequency of alternations of the transient surge.

If an arrester is to give protection to insulation in shunt with it, the arrester must relieve the abnormal electric pressure before damage is done to the insulation. Although tests are frequently made with the arrester and the insulation it is to protect in parallel, a more convenient method has been standardized and is known as the equivalent sphere gap test. Both the insulation and the arrester are compared by comparing each to the equivalent sphere gap.

The equivalent sphere gap of the oxide film arrester may be analyzed, as in other cases, into separate and distinct parts. First, there is the equivalent sphere gap of the main gap in series with the cells. Second, the equivalent sphere gap to initiate a discharge through the insulating film on the plate surface of the cell. Third, there is the equivalent sphere gap of the resistance drop of the current discharging through the powdered peroxide in its path. Fourth, there is the equivalent sphere gap of the inductance of the arrester.

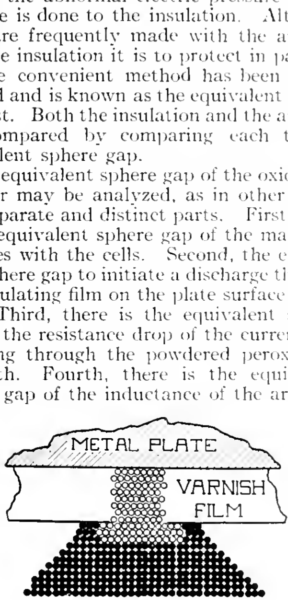


Fig. 4. A Magnified, Imaginary Representation of One of the Films on One Metal Plate. As shown the film is punctured by a spark and filled with a litharge plug which is represented by the open circles. The cross-section in the discharge path, a short distance away from the metal electrode, is sufficiently expanded to make the current of low enough density not to heat the peroxide to a temperature of reduction to litharge. The peroxide is represented by the solid dots and only those in the path of the discharge are shown. At the other electrode, not shown in this magnified diagram, a similar effect may be taking place although there is a difference between the positive and negative crators.

Commenting on these factors in their relation to this arrester, the main gap is itself a sphere gap which has the fastest spark of any practical gap. The gap setting, like that of the aluminum arrester, is only slightly above that of the normal voltage of the circuit.

The equivalent sphere gap of the film is several times greater than the thickness of the film because solid material has a greater dielectric spark lag than air, but with the multiple of the thickness of the film the equivalent sphere gap is still low. Since peroxide is a good conductor, the series resistance in the path of the discharge is insufficient to give an undesirable voltage drop. As to the inductance of the arrester, it has a minimum value due to the fact that each cell is only 0.5 in. long, as shown in Fig. 1, and the cells are placed one on top of another. In other words, the total length of the arrester which constitutes the inductance is short as compared to the necessary length of conductor from line to earth.

One of the obstacles that had to be overcome in the making of this arrester was the increase in the resistance after a great many heavy discharges had passed through it. The predominant reason for the increase seems to be explained by the following theory. The current passing through this small puncture in the film heats up very rapidly not only the powder but also the air contained within the interstices of the powder. The particles are thereby thrown out of contact with each other, thus producing a fluffiness. The decrease in the number of contacts decreases the actual cross sectional area of conduction hence increases the resistance. This raises the equivalent sphere gap. This action is accelerated, of course, by the giving off of the oxygen itself evolved in the reduction from lead peroxide to the lower oxide. If, however, this same arrester be jarred violently or the filling powder be compressed, or any other method utilized to restore the particles to their previous intimate contact, the equivalent needle gap will fall again. While increased fluffiness appears to be the predominant cause of change of the equivalent sphere gap, the increased thickness of the film of litharge at the point of puncture of the film is finally a factor of moment. The total area of the film must be sufficient to give a reasonable number of years of life to the arrester. There are other factors relating to the details of manufacture which give a limited degree of control over this change in equivalent sphere gap.

In all the commercial oxide film arresters used for alternating current the power factor is nearly unity. For special purposes, however, the power factor can be modified [illegible] from 10 per cent to unity. This is obtained by combining with the [illegible] oxide other [illegible] materials. This [illegible] has been made use of [illegible] has not been found desirable [illegible] arrester.

[illegible] an arrester operating under [illegible] been made which comprises in essence one or more metal electrodes covered with an insulating film, and separated by a conducting powder which has the peculiar characteristic of becoming a non-conducting powder upon the application of heat. Voltage higher than that which can be withstood by the insulating film punctures it in one or more points of about 0.005 cm. diameter. Dynamic current flowing gives a high current density in the conducting powder adjacent to these punctures which in turn heats it up rapidly, reducing the powder to a nonconductor, and sealing the holes in the film. The powder being a poor heat conductor localizes this action, so that very little more powder is reduced than is actually necessary to seal up these minute punctures.

The critical spark voltage and that part of the equivalent sphere gap controlled thereby is a function of the thickness and kind of material used for the film.

Comparison of the "Oxide Film" with Well-known Arresters

The earliest form of non-electrolytic film arrester was known as the dry aluminum arrester.* It was a direct attempt to utilize the dry film which forms on the surfaces of pure aluminum immediately after it comes in contact with the oxygen of the air. The hydroxide film is easily formed in electrolyte and on drying becomes a dry film which gives sufficient action to prevent a discharge up to a given critical voltage, depending upon the thickness of the film. The film can also be formed by a spark or arc of a conductor in contact with a plate. Naturally this conductor should be of a non-metallic nature. In the earliest form tried powdered carbon was used mixed with dioxide of manganese which gives a liberal supply of oxygen at the heated point.

One of the objects of the development of this arrester was to decrease the cost of manufacture and it was found with the new principle involved in the oxide film arrester, where the powder furnishes the film rather than the plate, that the aluminum could be replaced by a cheaper metal, such as steel, and, as already described, the initial film known in the early stages of development as the "paint skin" type could be furnished by a layer of varnish. On first sight, knowing the extreme thinness of the hydroxide film on wet aluminum cell it might not seem that the dry cell would give the same general characteristics as the wet cell. But a comparison of the volt-ampere curves shows the same general characteristics. For a-c. voltages of 300 volts average per cell the current in the dry cell is of negligibly small value up to 40 milliamperes. The power factor is nearly unity and the current flow is due to very slight leakages through the films. In the case of the aluminum electrolytic cells there is an equivalent condition, the d-c. leakage current of the order of one milliampere being due to leaks through the hydroxide film. In the a-c. aluminum arrester the leakage current on the plate area used is much greater, due to the destructive action of the alternating current on the hydroxide film. Furthermore, the wet cell with its thinner film is a condenser of appreciable capacitance which takes a charging current of about 0.5 ampere at 60 cycles. When the voltage reaches a certain critical value which is between 300 and 400 volts for the wet aluminum cell and between 300 and 500 for the oxide film cell (or higher if the paint film is made thicker) the current is allowed to pass freely through the cells, limited only by the ohmic resistance of the the cell independent of the film. Since the oxide film arrester has no dissolution of the film, as occurs in the wet aluminum cell, charging is not only unnecessary but undesirable. This extends the use of the oxide film arrester to localities where there are no attendants.

Although the wet aluminum plate becomes frosted to an appreciable thickness by the passage of current in long use, the actual thickness of the film, as represented by the critical voltage, is not changed. In the oxide film arrester, however, the film less than one 1 mil thick (0.025 mm.) initially thickens up by the addition of successive spots of litharge for each successive discharge. This represents the wear on the arrester and limits its total life. Fig. 3 shows comparative volt-ampere characteristics of the oxide film arrester and the a-c. aluminum arrester. Since both of these arresters have a leakage current which wears the plates of the cells when alternating current is supplied, it is necessary, as previously stated, to place a spark gap in series with the cells. This spark gap is set at a value slightly above the normal potential of the circuit so that nothing but abnormal voltages will cause a discharge.

The foregoing data show that the oxide film arrester has general characteristics closely like the standard aluminum electrolytic arrester. It has the obvious advantage which comes from being dry rather than wet; it will not congeal, and needs no daily charging.

* U. S. Patent, E. E. F. Creighton.

In making the characteristic volt-ampere discharge curves the oxide film arrester does not lend itself as readily to the test as the wet aluminum cell. While its critical film voltage is evident, the change from no conduction to full conduction is more sudden. Therefore, the discharge rate at double potential is best shown by throwing double potential on the cell and subsequently reducing the voltage to its normal value per cell. This gives a very considerable quantity of electricity through the cells and is a severe test.

In order to alter conveniently the voltage from double value to normal value the circuit is arranged as shown in Fig. 5. The object of the connections may be briefly stated: A transformer with two coils in series impresses voltage on the arrester and then the contacts of the arrester are automatically shifted to one coil giving half the voltage. A heavy pendulum closes switch S-1 and sets the oscillograph into operation. The full voltage of the transformer is thrown on to the oxide film arrester under test, marked O-F, which has a number of cells sufficient only for half the voltage of the transformer. In other words this throws double voltage on to the arrester and the heavy current passing through the cells causes fuse F-1 to blow. The operation of this fuse short-circuits half the transformer and throws the other half across the arrester. This is done by means of gaps and fuses as follows. When the expulsion fuse F-1 blows, the conducting gases are shot into the open gap G-1 which closes the circuit through fuse F-2 to the mid-point of the transformer. This short circuit on half the transformer causes fuse F-2 to blow and the hot gases discharging from fuse F-2 close the gap G-2 which throws the mid-point of the transformer on to the arrester through the switch S-2 which is closed just previous to starting the test. These several operations occur with a rapidity depending upon the size of fuses used. It is possible by this means to throw momentarily 22,000 volts on an 11,000-volt arrester and note the character attending its discharge and recovery. Fig. 6 shows such an operation on an oxide film arrester. The initial discharge current is 40 amperes during the first half cycle due to the point it strikes in the descending wave; during the second half cycle it is 106 amperes. After the third half cycle the litharge film has so completely sealed up the path of discharge that the current is too small to show on the oscillogram. The leakage current with no series gap is of the order of a few milliamperes.

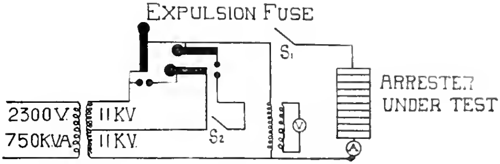


Fig. 5. Arrangement of Three Expulsion Fuses which short-circuit gaps in the path of discharge to first throw double voltage on an arrester under test and then reduce the voltage to normal value by shifting the contacts on a transformer from full coil winding to half coil winding.

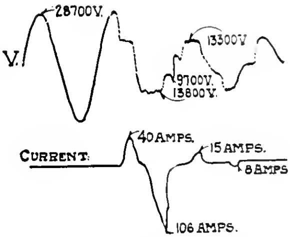


Fig. 6. Operation of an Oxide Film Arrester on double dynamic voltage initially and its recovery on normal voltage. The upper record with a peak voltage of 28,700 volts shows the arrester connected to the circuit as the voltage wave starts to decrease on its third peak. The voltage immediately drops to the critical value of the cells, about 13,500. On the lower record the current is seen to rise to 40 amperes. On reversal of the voltage to 13,800 in the negative direction as shown by the upper record, the current as shown by the lower record rises to 106 amperes. The switching operations produce several electro magnetic kicks as shown by the irregular voltage wave as it rises in the next cycle to 13,300 peak value. At this lower applied voltage the current in the series of cells, as shown by the lower record, is 15 amperes. In the subsequent half cycle the current rises only to 8 amperes. In the last half cycle of voltage shown, where the switching operation is complete, and the wave assumes its normal smooth form, the current in the cells is too small to be registered by the oscillograph. Its value is of the order of milliamperes. This figure is a copy of an oscillogram. The copy was made desirable because of overlapping of the discharge on the two ends of the film.

Methods for More Efficiently Utilizing Our Fuel Resources

PART XXI. THE COAL FIELDS OF THE UNITED STATES*

By Marius R. Campbell

United States Geological Survey

The last installment in this series contained statistics of the total supply of coal available in the United States and other countries, and also the rate of consumption in the United States. This installment gives detailed statistics of the available reserves, the present production for each coal region and province in the United States, and also a map of the United States showing all the known coal deposits, together with the quality of the coal in each region. The classification of the different ranks of coal is explained and diagrams are given to illustrate the variation in composition. A study of the statistics will indicate that we have been drawing most heavily on our limited resources of high-grade coal and have left vast reserves of low-grade coal undeveloped. Previous installments in this series have called attention to methods for efficiently utilizing these vast undeveloped fuel resources.—Editor.

Purpose and Scope of Report

The growing demand for fuel and the probability that sooner or later the United States will be called upon to furnish supplies to less favored countries has made it desirable for the Geological Survey to take stock of the country's fuel and to determine the quantity, quality, and geographic distribution of the coal still in the ground and available for future use.

The first effort to give to the public a comprehensive description of the great coal-bearing areas of the country was made by the Geological Survey in 1902, by the publication, in the Twenty-second Annual Report of the Director, of twelve papers dealing with the coal-bearing areas of the United States, including Alaska. Unfortunately, this series of papers, although exceedingly interesting and valuable as presenting a summary of the then existing knowledge of some of the coal fields, was lamentably incomplete.

Up to the year 1905, the United States Geological Survey had made no effort to examine and map systematically the coal fields of the country, especially of the West; but a number of fields had been specially examined or had been mapped as a part of the general plan of making a geologic atlas of the United States. This lack of activity in the examination of the coal resources was due largely to the lack of interest in such work shown by coal operators, owners, and consumers, as it was then generally regarded as unnecessary in the development of a coal-bearing tract to have any geologic information regarding the lay of the beds and the quality or quantity of the coal, and the consumer purchased his coal with but little thought as to whether or not he was getting the best available fuel for the particular use to which he expected to devote it.

About that time, however, the public began to awaken to the realization of the need of better utilizing the fuel supply, and to the further realization that great frauds had been perpetrated in the western states in procuring valuable coal lands under the homestead act and laws other than the coal-land law.

In anticipation of an action to put a stop to such frauds and to bring about a better conservation of the fuel resources of the country, the Geological Survey had begun in 1905 the systematic examination of coal fields in the public land states and by 1908 had made sufficient progress in that work to issue the first reasonably accurate map of the coal fields of the country, on a scale of about 120 miles to the inch.

The making of this estimate, crude though it was, marked an important step in the investigation of the nation's resources, for it was the first attempt to make a quantitative estimate that would enable the public to calculate the length of time the fuel supply might be available.

The next attempt to improve upon the old maps of the coal fields and the estimates of the reserves they contained was made by the writer on invitation of the executive committee of the International Geological Congress for its twelfth session, at Ottawa, Canada, in 1913.

Although the volumes published by the Twelfth International Congress are monumental and constitute a remarkable achievement, it was at once realized that they are very inadequate for practical use, and that they should be supplemented by more detailed reports on all the countries as soon as possible. Since the publication of the descriptions of the coal fields of the United States in the Geologi-

*Abstract from Professional Paper 100-A, U. S. Geological Survey, 1917.

cal Survey's Twenty-second Annual Report, in 1902, a large amount of geologic work has been done in the coal fields of this country. The Survey has each year mapped, either in a reconnaissance way or in detail, many thousands of square miles of coal territory in the public land states of the West, and in addition has been carrying on detailed work in many of the eastern fields.

In view of the great amount of work that has been done since the previous summary was made, it seems opportune to sum up again the existing knowledge regarding the extent and quality of the coals in the various fields. In order to give this report the greatest value and standing, it is proposed, so far as practicable, to have the description of each natural area prepared by the geologist who is most familiar with the field and best acquainted with the local conditions.

As the reports are to be prepared by many authors, it is impossible to assemble all the material at one time, so the state reports will appear as separates as soon as they are ready and will then be included in the final volume or volumes.

RANKS OF COAL

Methods of Classification

In this report the word "rank" will be used to designate those differences in coal that are due to the progressive change from lignite to anthracite, a change marked by the loss of moisture, of oxygen, and of volatile matter. This change is generally accompanied by an increase of fixed carbon, of sulphur, and probably of ash. When, however, one coal is distinguished from another by the amount of ash or sulphur it contains, this difference is said to be one of grade. Thus "a high-grade coal" means merely one that is relatively pure, whereas "a high-rank coal" means one that is high in the scale of coals, or, in other words, one that has suffered devolatilization and that now contains a smaller percentage of volatile matter, oxygen, and moisture than it contained before the change occurred.

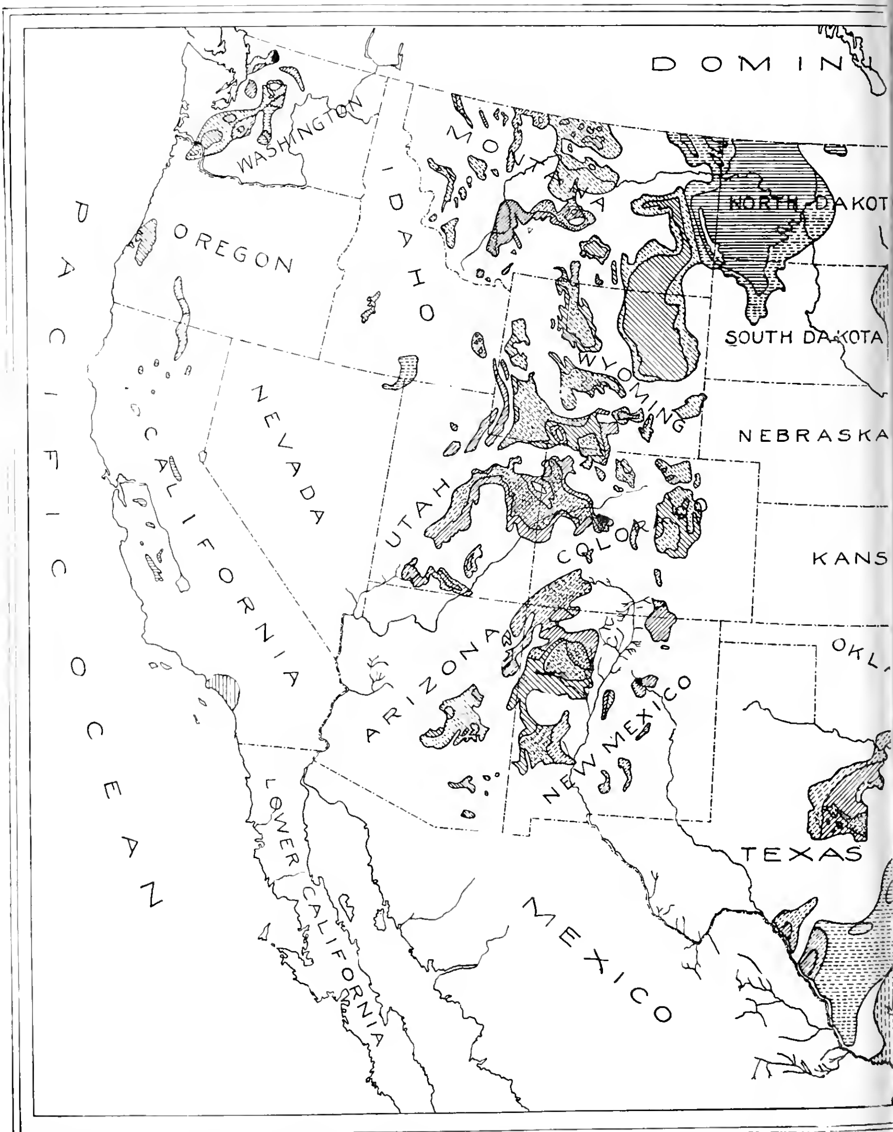
Within the boundaries of the United States there are all ranks of coal, from the coarse, woody lignite of North Dakota and eastern Montana to the highest rank of anthracite in the fields of eastern Pennsylvania. From the earliest days of coal mining in this country it has been recognized that coals differ greatly, not only in the percentage of ash which they contain, but also in their inherent composition. Although the latter distinction was recognized, little or no attempt was made to determine the reason for the difference or the criteria for fixing the limits of different groups of coals. The first serious attempt in this country to devise a scientific basis for the classification of coal was made by Persifor Frazer, Jr., of the Second Geological Survey of Pennsylvania, under the direction of J. P. Lesley. Frazer* listed most of the commercial coals of the state and then compared the trade distinctions with the "fuel ratio" (the quotient of the fixed carbon divided by the volatile matter of the proximate analysis). He found that there were in use at that time the rank names of anthracite, semianthracite, semibituminous, and bituminous. He found that in practice the fuel ratios of the coals of the different groups overlapped, but he concluded that these ranks might be established with the following limits:

	Fuel Ratio
Anthracite	100 to 12
Semianthracite	12 to 8
Semibituminous	8 to 5
Bituminous	5 to 0

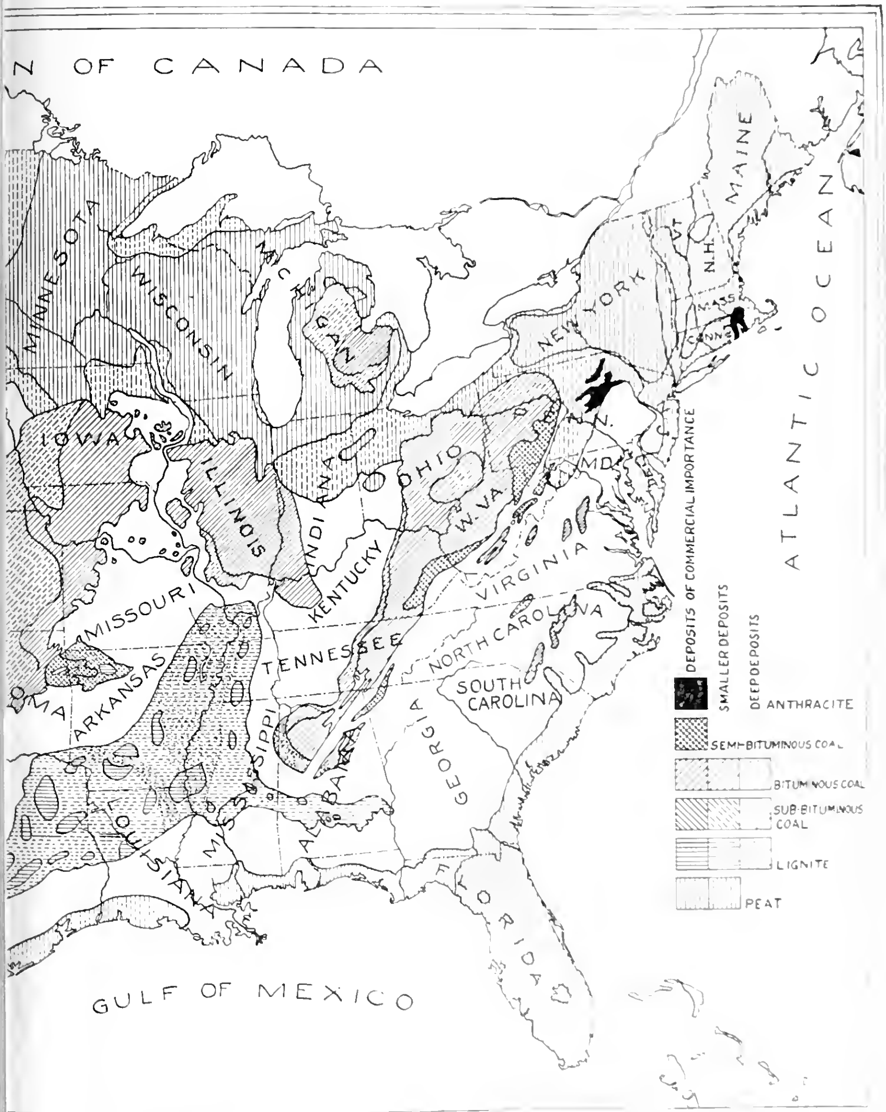
These ranks, with the boundaries fixed provisionally by Frazer, serve very well for Pennsylvania and for the coals of the great Appalachian trough, extending from northern Pennsylvania to central Alabama, but they do not apply to the great mass of western coals which at that time were of little or no importance. Most of the coals in the Appalachian region and those in the upper Mississippi valley are of carboniferous age and hence are very old; but the coals of the West are cretaceous and even tertiary in age and hence, when compared with Appalachian coals, are very young indeed. A difference in character was recognized, and as the western coals are generally inferior they were lumped together and called merely "lignite." The term "lignite" is undoubtedly appropriate for many of the low-rank coals of the West, but it certainly is not appropriate for black, shiny coals that show little trace of woody texture and are capable of producing a coke of fairly good quality. Nevertheless such coals were called lignite and relegated to the lowest rank among coals.

Several persons have attempted to devise schemes of classification based upon chemical composition by which a certain coal could be referred to its proper place merely by means of its chemical analysis, but so far no scheme of this kind has been devised that is applicable to all ranks of coal. Some scheme like Frazer's suits admirably one part of the

* Pennsylvania Second Geol. Survey Rept. MM, [illegible] 1879.



The coal fields of the United States, together with the areas containing peat deposits of commercial value Nearly all the states extent. The peat and lignite deposits are located in sections where high-grade coal must be obtained from a distance. The same is



have some form of solid mineral fuel which can be produce [illegible] thereby relieving our transportation facilities [illegible] true of the Rhode Island graphitic anthracite field column but can not be made to fit the other part. Schemes of this kind are so unsatisfactory that the United States Geological Survey has finally decided that it is practically impossible to classify all ranks of coal according to their chemical composition, and that it is necessary to supplement chemical by other criteria. Accordingly Frazer's scheme, with some necessary modification to make it agree more closely with modern trade practices, has been adopted for the higher ranks of coals, and physical characteristics have been used for the lower ranks. Thus, in the West no one questions that there is coal of the rank of lignite, but it is difficult, if not impossible, to specify what a lignite is in terms of its chemical constituents. Similarly, in the Rocky Mountain region, where the low-rank coals are abundant, there is no question that there is a difference between brown, woody, or amorphous lignite, and shiny, black subbituminous coal, but this difference is one that is not clearly defined by available chemical criteria. There is, however, a marked physical difference, although there is no sharp line of demarcation between them. Thus subbituminous coal is black and shiny, whereas lignite is dull and generally woody in texture; subbituminous coal has a greater heating value and carries less moisture than lignite. Altogether the difference between the two is so marked that they are known by different names in the trade, and for that reason, if for no other, they should be classed differently.

In a like manner the distinction between subbituminous and bituminous is not sharp and does not show in a chemical analysis. Subbituminous coal generally carries more moisture than bituminous, but there are so many exceptions to this rule that it has very little value as a means of distinction. There is, however, one marked difference by which they can always be separated, and that is the difference in their behavior under weathering, and as this difference has a marked effect upon their commercial value and use, it seems to be a legitimate criterion for separating them into the two ranks, subbituminous and bituminous. The difference in the effect of weathering is due primarily to a difference in the percentage of moisture in the coal, but, as stated above, the percentage of moisture is variable. Subbituminous coals, however, in general contain more moisture than bituminous coal, and on weathering lose their moisture readily. This loss of moisture results in shrinkage and the formation of incipient cracks, which do not conform to the few joint faces but tend to run irregularly. On the other hand, the bituminous coals generally contain a smaller percentage of moisture, so that they shrink very little when they are suddenly dried. They may be very highly jointed and may fall to pieces readily when mined and handled, but their breakage is due to the inherent weakness of the coal, and the cracks almost invariably correspond with the joint faces.

By using these criteria (part chemical and part physical) it is possible to classify coals, and not only to define the general characters of the different groups but to delimit them with considerable accuracy. The United States Geological Survey recognizes the following ranks.

Anthracite

Anthracite is generally well known and may be defined as a hard coal having a fuel ratio (fixed carbon divided by the volatile matter) of not more than 50 or 60 and not less than 10. Most of it is mined in eastern Pennsylvania, where its peculiar quality is due to regional metamorphism — that is, to the crushing stresses that affected the crust of the earth when the rocks were thrown into the great folds that characterize this region. Small areas of anthracite occur in the West, but generally these coals have been converted to anthracite by the heat of some mass of igneous rock that was thrust into the other rocks while it was in a molten condition. Many such masses take the form of thin sheets, which were forced in between the beds of the other rocks, and consequently for some distance they may lie parallel with the coal beds. If a coal bed is cut by the igneous rock it may be burned to ashes, made into coke, or converted to anthracite. The product will depend on the presence of air, the intensity of the heat, and the length of time the coal was subjected to the influence of the heated mass. Anthracite is an almost ideal domestic fuel, but it is not well adapted to steam raising unless an absolutely smokeless coal is needed. Many people believe that anthracite has greater heating value than any of the other ranks, but this is not true, as can be seen by reference to Fig. 1. Largely on account of its low heating power, anthracite is not an economical fuel for steam raising or for use in general manufacturing.

Semianthracite

Semianthracite is also a hard coal, but it is not so hard as true anthracite. It is high in fixed carbon, but not so high as anthracite. It may be defined as a hard coal having a fuel ratio ranging from 6 to 10. The lower limit is uncertain, as it is difficult to say where the line should be drawn to separate "hard" from "soft" coal and at the same time to divide the two ranks according to their fuel ratio. Some hard coals of the anthracite type have a fuel ratio as low as 6.5 or 7, whereas some of the soft coals have a fuel ratio as high as 7 or perhaps more. For this reason it is probable that fuel ratio alone can not be depended upon to separate these two ranks, but that physical properties also may have to be taken into consideration. The change of ordinary soft coal to semianthracite is due to the same causes that produced anthracite, except that the process has not been carried so far in semianthracite, possibly because the action has not been so intense. There is very little semianthracite in this country, so it is only a small factor in the coal trade. Such semianthracite as is mined reaches the consumer generally under the name "anthracite" and is masquerading under false colors.

Semibituminous

The name "semibituminous" is exceedingly unfortunate, as literally it implies that this coal is half the rank of bituminous, whereas it is applied to a kind of coal that is of

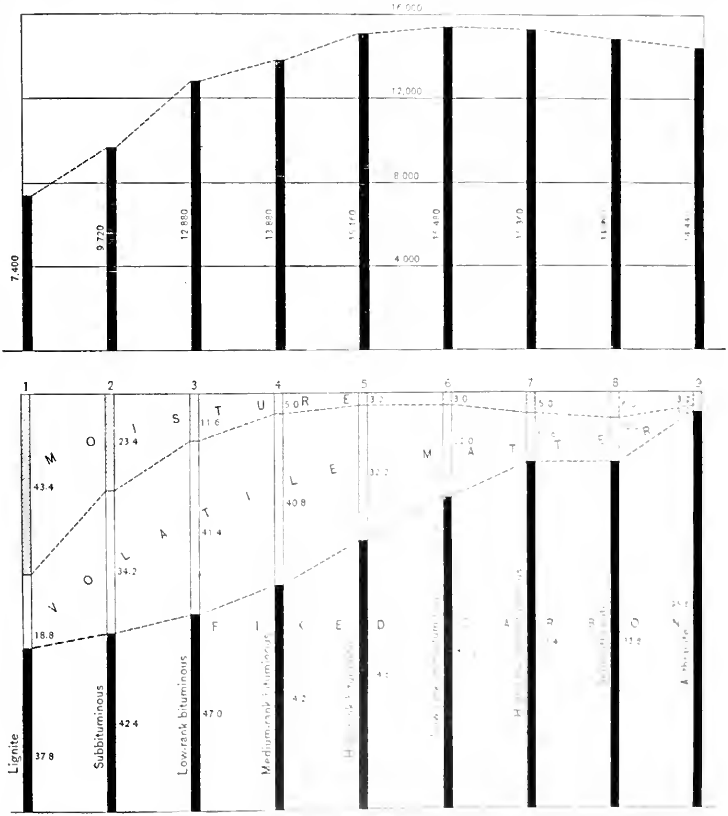


Fig. 1. Diagrams Showing the Chemical Composition and Heat Efficiency of the Several Ranks of Coal

Upper Diagram: Comparative heat value of th[illegible]
Lower Diagram: Variation in the fixed carbon, v[illegible]
puted on samples as received, on the ash-free basis

higher rank than bituminous—really superbituminous. Semibituminous coal may be defined as coal having a fuel ratio ranging from 3 to 7. Its relatively high percentage of fixed carbon makes it nearly smokeless when it is burned properly, and consequently most of these coals go into the market as "smokeless coals." The best coal of this type has a heating value greater than that of any of the other ranks and is consequently best adapted to raising steam and to general manufacturing that requires a high degree of heat. It is regarded as the best coal for steamship and especially for naval use, as it is nearly smokeless and requires less bunker space per unit of heat than other coals. The coal is minutely jointed and is therefore tender and friable. In fact, it is so friable that in mining a large percentage of fine coal is produced, and in transportation many of the lumps are broken to pieces, so that by the time it reaches the consumer, especially if it has been transshipped, it is generally in small pieces. This fineness is by many regarded as detrimental, because the public is accustomed to lump coal which will stand transportation without crushing, but when this coal is used with mechanical stokers and with a grate adapted to its use the fineness of the coal is not disadvantageous. The great bulk of this kind of coal is in the eastern fields, but some is found in the West, where it has been subjected to a slight amount of regional metamorphism or has been heated by some igneous mass.

Bituminous

The term "bituminous," as generally understood, is applied to a group of coals having a maximum fuel ratio of about 3, and hence it is a kind of coal in which the volatile matter and the fixed carbon are nearly equal; but this criterion can not be used without qualification, for the same statement might be made of subbituminous coal and lignite. As noted before, the distinguishing feature which serves to separate bituminous coal from coals of lower rank is the manner in which it is affected by weathering. Bituminous coal is only slightly affected chemically by weathering unless it is exposed for many years, and then, although it consists of small particles, each particle is a prismatic fragment, whereas coals of lower rank break into thin plates parallel with the bedding.

The definition given above might not indicate that the bituminous rank is a large one, but when it is examined critically it is found to contain a great variety of coals—coals having really little in common with one another. Many attempts have been made to subdivide this great group, but so far no scheme proposed has met with general approval. Many of the better coals of this group will coke or are being coked, but coking coals are not limited to the bituminous rank, for some of the best coke made in the United States is produced from semibituminous coal. Not only is the upper limit of the coking group uncertain, but the lower limit is equally difficult to determine. If the coking property had some definite relation to the chemical composition of the coal as it is at present determined, there might be some hope of establishing a class of coking coals by chemical analysis, but no one can say just why a coal will coke, so an actual test in an oven is required to determine whether or not a coal will coke.

Gas coals have been in great demand and such coals must be high in volatile matter, so as to make on distillation a large volume of gas; and as this gas must be relatively free from sulphur the coal from which it is made must contain a very small percentage of that element. In recent years the making of gas for illuminating and heating has undergone a great change, water gas largely taking the place of the gas distilled from coal; and as this gas requires no particular quality of coal, the demand for "gas coals" has been greatly reduced and probably in the near future will disappear.

Cannel coal is very rich in volatile matter, is generally high in hydrogen, and therefore burns with a great heat and a long flame. It is essentially a gas-making coal and in the early days was used extensively for this purpose, as well as for the distillation of oil. As a source of oil it could not compete with petroleum derived from wells, and soon after oil was discovered in the earth in 1859 the business of distilling oil from coal in this country was discontinued. Cannel coal owes its richness to the fact that it is composed almost entirely of the spores, spore cases, seed coats, and resinous or waxy products of such plants as lived at the time of the existence of the coal swamp. In such swamps, as in those of today, there was doubtless in places open water into which the spores and seed cases floated and, becoming water-logged, sank to the bottom and in time produced cannel coal. The absence of woody material in such coal gives it a regular texture and grain that are not found in any other coals. As a result, it breaks like glass, with a conchoidal or shell-like fracture, and owing to its richness in inflammable material the best of it will ignite readily when a lighted match is held in contact with a small splinter of it. As the nature of cannel coal is due to the kind of material of which it is composed, it follows that there may be all kinds of cannels, corresponding in a general way with the various ranks of coals.

Subbituminous

The term "subbituminous" is adopted by the Geological Survey for what has generally been called "black lignite," a term that is objectionable because the coal is not lignitic in the sense of being distinctly woody, and because the use of the term seems to imply that this coal is little better than the brown, woody lignite of North Dakota, whereas many coals of this rank approach in excellence the lowest grade of bituminous coal. Subbituminous coal is generally distinguishable from lignite by its black color and its apparent freedom from distinctly woody texture and structure, and from bituminous coal by its loss of moisture and the consequent breaking down or "slacking" that it undergoes when subjected to alternate wetting and drying. As the percentage of moisture is an important matter in buying and shipping coal, and as the slacking on exposure to the weather makes it necessary to ship in box cars and to guard carefully against spontaneous ignition, there is a great commercial difference in these two kinds of coal which the Geological Survey has recognized by putting them in different ranks. Despite the many drawbacks in the shipment and use of subbituminous coal, it has found a ready market in much of the western country, because it is a very clean domestic fuel and ignites with little difficulty.

Subbituminous coals differ considerably in chemical composition and in physical appearance. Some are banded like much of the bituminous coal, and some are essentially cannel in physical and chemical make-up. In general, the cretaceous and younger coals of the West contain a smaller percentage of sulphur than the older coals of the East, and as some of them are high in volatile matter they would doubtless be excellent coals for making gas, either illuminating gas or producer gas, for generating power.

Lignite

The term "lignite," as used by the Geological Survey, is restricted to those coals which are distinctly brown and either markedly woody or claylike in their appearance. They are intermediate in quality and in development between peat and subbituminous coal. As the moisture of lignite as it comes from the mine generally ranges from 30 to 40 per cent, its heating value is low; and the consumer can not afford to pay freight for any great distance on so much water. Also it parts with much of this moisture very readily when exposed to the weather and so falls to pieces or slacks much more readily and completely than subbituminous coal. On this account it is more likely to ignite spontaneously and must be handled even more carefully than subbituminous coal and stored in a place where it will not be exposed to alternate wetting and drying. Lignite is mainly marketed near the mine, as a domestic fuel, but at a few places in North Dakota and Texas it is shipped to near-by towns and used for general manufacturing purposes.

At the Government testing plant at the St. Louis Exposition, North Dakota lignite was found to be an excellent fuel for making producer gas, and probably in the future it will be much more largely used for producing power than it has been in the past. Just how this will be accomplished is difficult to determine, but it is possible that large producer plants may be erected at the mines and the lignite converted into electric energy and delivered by long-distance transmission lines to towns within a radius of 200 miles or to the railroads in this region or in contiguous territory. Lignite has recently been used in powdered form, and it may possibly be better utilized in this way. As some of the Texas and Arkansas lignites are in effect undeveloped cannel coals, it seems possible that when the supply of petroleum is much less than the demand, the lignite may be used for the distillation from it of oil and the various by-products that are now obtained in Scotland from oil shale. Lignite can also be manufactured into hard briquets, which make an excellent fuel, but so far the cost of manufacture has been prohibitive.

Comparison of the Different Ranks

Fig. 1 is a graphic representation of the proximate chemical composition of the various ranks of coal and of their heat-producing values. The lower diagram shows the fairly regular increase in fixed carbon from lignite to anthracite, though it must not be supposed that the lines for all coals are as simple as those shown. The diagram is based upon actual analyses, however. No. 1 represents the analysis of a typical North Dakota lignite which as it comes out of the mine has a moisture content of about 40 per cent. It also contains about 5.5 per cent of ash, but as ash varies irregularly without regard to the rank of the coal the analysis has been recalculated to the ash-free basis, thus eliminating ash from consideration. All the other analyses have been similarly recalculated. No. 2 represents a subbituminous coal from Wyoming; Nos. 3, 4, and 5 represent various ranks of bituminous coal, the lowest one being from Indiana, the second from Ohio, and the third, or highest, from the Pittsburgh district of Pennsylvania; Nos. 6 and 7 represent semibituminous coal from the Windber district of Pennsylvania; No. 8 represents semianthracite; and No. 9 represents some of the best anthracite of the Pennsylvania region. The diagram shows clearly that the fixed carbon increases very markedly from lignite to anthracite; that the moisture of the higher-rank coals is small and about the same quantity in each, but increases rapidly from medium-rank bituminous coal to lignite; and that the greatest development of volatile matter is not at either end of the series but in the lower ranks of bituminous coal.

The upper diagram represents the heat value of the same coals on a similar ash-free basis. Therein, the best coal for heat production is conclusively shown to be No. 6, or low-rank semibituminous coal. Anthracite commands a higher price than soft coal because of its suitability for domestic use and because of its freeom from smoke, soot, and waste.

From the diagram it might be inferred that the heat value of a coal depends directly upon the amount of fixed carbon that it contains, but this can not be true, for the heat value of pure carbon is only 14,580 B.t.u.,* whereas coal No. 6 has a heat value of 15,480 B.t.u. Coal derives its heat value mainly from two elements, carbon and hydrogen, the carbon having a heat value of 14,580 B.t.u., and the hydrogen a heat value of 62,000 B.t.u.* The greater heating power of the low-rank coals as compared with anthracite is due to the fact that these coals contain a considerable quantity of available hydrogen,† which when burned produces a much greater heat than the same weight of carbon.

* Richards, J. W., Metallurgical Calculations, p 16, 1906.

† W. S. Parr (The Composition and Character of Illinois Coals, Illinois Geol. Survey Bull. 3, p. 37, 1906) defines available hydrogen as follows "By available hydrogen is meant that part of the hydrogen content which is free to enter into combination with oxygen for the production of heat, as distinct from that hydrogen present which already has . . . the necessary equivalent oxygen for the formation of water, and consequently [is] noncombustible."

Either diagram well illustrates the slight value of lignite as compared with the higher-rank coals and makes it possible to understand that Pennsylvania and West Virginia coal can be hauled by rail to Lake Erie, shipped by vessel to Duluth or Superior, hauled 400 or 500 miles inland, and then sold in direct competition with lignite mined in the vicinity.

CLASSIFICATION OF COAL AREAS OF UNITED STATES

For convenience in describing the areas underlain by coal-bearing rocks, some scheme of names and classification of areas is essential. Although coal areas might be subdivided or combined indefinitely, the Geological Survey recognizes four classes, which, beginning with the smallest, are called district, field, region, and province.

Coal District

"Coal district" is a term applied only to developed coal areas. It is already in common use in the trade for an area in which mining has been developed around a fairly definite center, but it also has been loosely used as synonymous with "coal field." A district is generally small, and the term is restricted to areas in which mines are developed continuously on a given bed or beds, and the coal is generally known in the trade by some distinguishing feature, such as a trade name, or by some physical characteristic upon which it is advertised and sold.

Coal Field

The term "field" is at present used very loosely, and in many ways it is not advisable to attempt its close restriction. As used by the Geological Survey, this term is applied to an area generally larger than a district, but still to a well-defined compact area. In this respect it differs from "region," the term for the next higher division. Small areas or basins that are separated from one another or from the main coal area are called fields, especially if their coal is of fairly uniform composition and value. "Field" is also applied to a certain area which has become prominent because of the kind of coal it produces, but which is not necessarily limited to certain centers of production.

Coal Region

As a matter of convenience, coal fields may be grouped into larger divisions called "regions." Such grouping is generally designed to bring together coal fields that have some feature or features in common, thus enabling them to be considered as a whole or separately as the problem may demand.

Coal Province

As fields are grouped into regions, so regions are grouped into much larger divisions, called "provinces." These are the Eastern province, Interior province, Gulf province, Northern Great Plains province, Rocky Mountain province, and Pacific Coast province. The grouping into provinces is made largely for convenience in considering broad questions of geologic age, geologic structure, quality of coal, and transportation. In a province, as in a smaller division, there is a certain amount of unity in the physical features of the coal fields of the province or in the quality of the coal. Some provinces contain all ranks of coal, and the fields are grouped together because of their geographic positions, their structural features, or the age of the coal beds.

THE COAL AREAS

Eastern Province

The Eastern coal province contains probably nine tenths of the high-rank coal of the country. It is considered as made up of the anthracite regions of Pennsylvania and Rhode Island, the Atlantic coast region of Virginia and North Carolina, and the great Appalachian region, which embraces all the bituminous and semibituminous coal of what is generally known as the Appalachian trough.

The Rhode Island anthracite region, although known since 1760, is of little economic importance, for the coal has never been mined for a long period on a commercial scale, and judging from its composition and the metamorphism of the surrounding rocks, it seems doubtful whether it will ever have more than a local value, if it is worked at all.

The Pennsylvania anthracite coal region is so well known that it needs little mention here.

The Atlantic coast region is of very little practical importance at the present time, for its coal beds are worked either not at all or on a scale so small as to be negligible. The Richmond field or basin, however, has the distinction of being the scene of the first development of bituminous coal in this country, mining having been begun there in 1787. The coal is generally of high rank, some being semianthracite, but the conditions of mining are not good, and the coal can not at present compete with the better coals of the Appalachian region.

The Appalachian region is the greatest storehouse of high-rank coal in the United States, if not in the world. The region is a compact area of coal-bearing rocks, which in general lie in a deep trough. The lowest coal bed, if present in the deepest part of the trough, would be about 2,000 feet below the surface.

The coal of the Appalachian region is generally of high rank but shows considerable variation, mainly in an east-west direction. The percentage of fixed carbon in the coals of Pennsylvania increases from west to east, and also the volatile matter decreases in the same direction. The result of this progressive change is that the coals on the eastern margin of the region are of much higher rank than are those on the western margin.

During the deposition of the coal beds the Appalachian region was doubtless a great swampy country near sea level, but even then it appears to have been in the form of a basin, whose deepest part was in western West Virginia. On account of this depression there was probably open water here, at least during part of the time when the coal beds were being deposited, for the coals are generally absent from this part of the region. These beds, if present, would be deeply buried, but their absence has been revealed by deep drilling done to find oil and gas.

Interior Province

The Interior province includes all the bituminous coal fields and regions near the Great Lakes, in the Mississippi Valley, and in Texas. It is made up of four distinct regions: the northern region (Michigan); the eastern region (Illinois, Indiana, and western Kentucky); the western region (Iowa, Missouri, Kansas, Oklahoma, and Arkansas); and the southwestern region (Texas).

As these regions, with one exception, are not near mountainous uplifts, the coals are of low rank, for little pressure has been exerted upon them, and their change or devolatilization has been only such as resulted from the long-continued pressure of the overlying rocks. This statement is eminently true of the northern and eastern regions, the Iowa and Missouri portions of the western region, and the southwestern region, but as the southern part of the western region is near or a part of the mountainous area of uplifted rocks in Arkansas, the coal beds have been materially affected.

The coals of the northern part of this province have a large moisture content, which of course produces low heating value and a generally poor coal.

The northern and eastern regions are in the form of wide, generally shallow basins in the coal-bearing rocks, the deepest parts of which lie near their centers, toward which the beds dip lightly from the margins. The coal-bearing rocks in the western and southwestern regions do not lie in basins, or rather they constitute the eastern margin or rim of the greatest basin on the continent—the basin of the Great Plains.

Although the coal of the Interior province as a whole is not equal in quality to that of the Eastern province, it is very extensively mined and is used for heating and for generating power in the many cities and towns of the Mississippi Valley and the Great Lakes. In fact, the presence of these extensive coal fields in proximity to the rich agricultural lands of this country and to the avenues of transportation—railroads, lakes, and rivers—has been largely instrumental in developing the great manufacturing centers of Chicago, St. Louis, and Kansas City and has been an important factor in the development of the railroad systems that gridiron this fertile country in all directions.

Gulf Province

The Gulf province is at present of slight commercial importance. The coal is mostly lignite, and it has been mined at only a few localities in the State of Texas. The same kind of lignite occurs in Arkansas, Mississippi, and Alabama, but, owing to the presence of high-rank coal nearby in the fields of Arkansas, western Kentucky, and Alabama, it has not been prospected except in a few areas. The lignite is contained in rocks of eocene (early tertiary) age, generally sandstone and clay, that are so soft as to make mining difficult and expensive.

The old idea that lignite is of recent formation and is of low rank because of that fact is generally true, but there are many exceptions. Some of the most valuable coal beds in the western states are of the same age as the Texas lignite, yet they are of high rank. A study of the coal fields of the United States shows clearly that, although age is a factor in the alteration of coal, it is generally not the principal one. The controlling factor is the presence or absence of disturbances in the rocky crust of the earth, either in the coal field or close to it.

The lignite of northern Texas and southern Arkansas is of better quality than that of the central part of Texas, the difference being due probably to the different conditions under which it was deposited. The lignite in the southern part of Texas seems to have been formed largely of trees and stems, which are clearly visible in the lignite today; but in the northern part of the State there appears to have been open water in which the accumulation of organic matter consisted mostly of spores, seeds, and spore cases that grew on the plants in the surrounding areas. Such wood as fell or drifted into the water decayed, for the most part, so that its resin contents fell to the bottom, there to mingle with the spores and other resistant detritus. The result is that this lignite is very rich in bituminous matter; it is sub-cannel coal or cannel coal in the process of formation.

Northern Great Plains Province

The Northern Great Plains province includes all the coal fields in the Great Plains east of the Front Range of the Rocky Mountains. In this province the rocks generally lie flat or are but little disturbed, and in consequence the coals are of low rank, being either lignite or subbituminous, except in a few of the basins near the mountains, where the forces that caused the upheaval have locally changed the coal to higher rank. This progressive increase in rank toward the regions of mountain making is apparent in this province, as may be seen not only by comparing the coals of the different fields or basins, but by comparing many of the coals within a basin, region, or field.

The largest coal region in this province is the Fort Union region, lying in North Dakota, South Dakota, Montana, and Wyoming. The northeastern part of this region consists of a very broad, flat basin, in which the dips on the margin are so slight as to be perceptible only by the aid of a level.

Throughout North and South Dakota and northeastern Montana the coal is a brown woody lignite with a moisture content, as it comes out of the ground, of 40 to 45 per cent, but in the vicinity of Miles City, Mont., the brown lignite begins to lose its apparently woody structure and to take on the black color and the general appearance of a subbituminous coal. The change is, however, very gradual, and throughout a zone 15 or 20 miles in width can be seen the mingling of the two types.

The subbituminous coal in southern Montana is of very poor quality, but farther southwest, in Wyoming, it improves until it reaches its best development in the vicinity of Sheridan, Wyo., where it has been mined extensively for a number of years. At this place the moisture content of the coal as it comes from the mine is only about 25 per cent, and for this reason alone its heating value is 30 per cent higher than that of the lignite of North Dakota.

Many of the coal beds in the Fort Union region are thick, those that are worked measuring from 3 to 40 feet. In almost every section of land that has been carefully examined there have been found a number of thick beds, so that the quantity of unmined coal or lignite in this region is very great.

The lignite and subbituminous coal of this region, as well as that of most of the other fields and regions of this province and of the Rocky Mountain province, ignite easily, and many of them have been burned along the out-crop.

There is very little mining in the Fort Union region, because the inhabitants are engaged chiefly in raising stock and farming, and there are no large towns or cities in which much manufacturing is carried on. The absence of manufacturing explains in part the lack of mining, but the greatest drawback to the establishment of mines is the poor quality of the lignite, which precludes its use as a fuel in many manufacturing processes. Although winter in this region is very severe and fuel is in great demand, those who have attempted to mine the lignite have found difficulty in marketing it in competition with high-rank Pennsylvania and West Virginia coal shipped over the Great Lakes and thence by rail to the lignite region. In the southwest end of the region, where the coal is of the subbituminous rank, the operators have been more successful in opening mines and in building up a large trade. The two centers of production are Sheridan and Glenrock, near Douglas, Wyoming.

Coal like that of the Sheridan district, though perhaps of somewhat better quality, is rather extensively mined in the Bull Mountain field, on Musselshell River. This field is comparatively new, and is small—having an area of about 1,000 square miles—but it includes a number of beds, some of which attain considerable thickness.

In the Milk River valley and along Missouri River south of the Bearpaw Mountains there is considerable coal, but the beds are generally thin or are only locally expanded into beds thick enough to be of present commercial value. The coal is generally subbituminous, but in places it is of the bituminous rank.

The highest-rank coal in this part of the province is that in the Great Falls and Lewistown fields, of Cascade and Fergus counties, Mont. This coal is bituminous and for a number of years was mined and coked at Belt to supply the copper smelters at Anaconda. The coking coal is limited, however, to this locality, and the manufacture of coke from it was discontinued several years ago. The coal contains a large percentage of impurities and has therefore not met with as ready a sale as was expected when the mines were first opened. The coal is mined somewhat extensively for steaming and domestic use in the region round about the mines.

Farther south, in Colorado, the next field of consequence is generally known as the Denver region. It is subbituminous and finds a ready market in and about Denver and Colorado Springs as a domestic fuel.

The Cañon City field is a small basin of coal-bearing rocks in the great re-entrant of the mountain front at Cañon City. Owing to its proximity to the mountain uplift the coal has been changed to the bituminous rank, but it carries so high a percentage of ash that its sale in competition with cleaner coals is difficult, especially for domestic use

The Raton Mesa region, in the southern part of Colorado and the northern part of New Mexico, contains the most valuable and highest-rank coal in this province. The Colorado portion is generally known as the Trinidad field and the New Mexico portion as the Raton field. The coal in the southern part of the region makes excellent coke, and the product of the ovens supplies most of the smelters in the Rocky Mountain province.

Rocky Mountain Province

Until within a few years the coal resources of the Rocky Mountain coal province were largely unknown except a few areas of high-rank coal in Colorado and neighboring states, which were exploited by some of the large steel companies or railroad corporations Since 1905 the United States Geological Survey has examined most of these fields, either in reconnaissance or in detail, and now the fields of this province are almost as well known as those of the Eastern or Interior provinces.

The Rocky Mountain province contains a greater variety of coal than any other province in the United States The coal ranges from lignite to anthracite though the prevailing ranks are subbituminous and low-grade bituminous. The coal is mined rather extensively, the greatest centers of development being Red Lodge, Mont., Rock Springs and

Kemmerer, Wyo.; Crested Butte and Durango, Colo.; Castlegate and Sunnyside, Utah; and Gallup, N. Mex.

In Montana the coal fields of the Rocky Mountain province are neither large in area nor of great commercial importance.

The most important area in this part of the state is the Red Lodge field, which, so far as Montana is concerned, might be considered in the Northern Great Plains province, because it lies east of the Front Range of the Rocky Mountains, but it is also the northern continuation of the Bighorn Basin region.

The coal of the Bighorn Basin is mostly subbituminous, but that in the lower coal-bearing formation, at the north end of the basin, in the vicinity of Bridger, Mont., is bituminous. The subbituminous coal, however, is of excellent quality, especially that mined at Red Lodge and Bear Creek, at the north end of the basin, and at Gebo, near the south end, and compares favorably with the best subbituminous coal of the Rocky Mountain province.

The Wind River Basin is of much the same character as the Bighorn Basin, except that the late tertiary formations more nearly conceal the coal-bearing rocks. For this reason less is known regarding the coal beds, which have been mined in only a small way. The coal is subbituminous and compares favorably with the coal of the same rank in adjacent fields.

The Green River region is a great irregular basin in southwestern Wyoming, in which the Rock Springs dome rises like an island in the sea. This region contains, besides the Green River Basin proper, a basin lying between Rock Springs and Rawlins, which extends southward and terminates in a point near Steamboat Springs, Colo. The rocks of this basin include four coal-bearing formations, which are generally well exposed in the upturned rim and in the Rock Springs dome, near the center of the basin. Several kinds of coal occur in the basin, ranging in rank from subbituminous to anthracite. The coal at Rock Springs, Wyo., may be regarded as the best type of bituminous coal in this region.

This enormous basin is one of the largest and most important coal regions in the Rocky Mountain province. It embraces an area of about 17,000 square miles and contains four coal-bearing formations, each of which carries from four to twenty coal beds, ranging in thickness from 2 feet to 20 or 25 feet. It is true that the coal in many areas of this region lies so deep that it may never be worked, but after excluding all such areas it is estimated that at least 6000 square miles is underlain by coal beds that can be mined when the demand for fuel is sufficient to warrant the expenditure necessary for sinking deep shafts. The quantity of coal in the ground in this region is enormous, probably exceeding that in any other region of similar area in this country. There are only two centers of mining in the Green River region. The most important is Rock Springs, Wyo., on the Union Pacific Railroad, where mining has been carried on since that road was completed in 1869. The other mining center has recently developed in the vicinity of Steamboat Springs, Colo., on the Denver & Salt Lake Railroad ("Moffat road").

West of the Green River Basin is the Hams Fork coal region, which consists of a number of folds of coal-bearing rocks. These extend nearly northward from the southwest corner of Wyoming for a distance of 200 miles. The coal is high-rank bituminous and subbituminous. The coal beds vary considerably in thickness, the largest one of subbituminous rank measuring at one place 84 feet of clear coal. This is the thickest coal bed that has been mined or prospected at the surface in the United States. Somewhat thicker beds have been reported in drill logs in other regions, but the uncertainty of determining the thickness and character of beds penetrated by a churn drill renders such a report of doubtful value. The greatest center of mining is at Kemmerer, Wyo., and this coal is regarded as the best that is produced in the state.

South of the Uinta Mountains lies a great, irregular basin-shaped coal region, which is called the Uinta region. The coal-bearing rocks form the rim of this great troughlike depression. From the rim they dip toward the middle and are there deeply buried by later formations. The coal varies considerably in quality, being best at the two extremities of the region. The coals in the vicinity of Crested Butte have been greatly altered, partly by the mountain-building forces and partly by the volcanic material that has been poured out in this area, and as a consequence some of the coal is high-grade anthracite and some belongs to lower ranks. On the rim, especially to the north, the coal changes within a short distance to subbituminous, and this rank characterizes the coal along the north rim. The coal on the south rim is generally bituminous, and west of Green River it improves rapidly in quality and increases in quantity to Castlegate, Utah, where there are many beds of high-grade bituminous coal.

The coal beds of the Uinta Basin are not so numerous nor so extensive as those of the Green River Basin, to the north, but even this basin contains an enormous quantity of coal. The area of the basin is about 16,500 square miles, a little less than the area of the Green River Basin, and the part in which the coals are accessible for mining is about 5,750 square miles. The coal beds are most numerous at the two extremities of the region, and naturally those parts contain the greatest quantity of coal. At Newcastle, on Grand River, 109 feet of coal in workable beds has been measured, and the beds at the western extremity are probably just as thick. The thickest bed reported is 40 feet, but beds that measure from 6 to 15 feet are fairly common.

Pacific Coast Province

The coal in the Pacific Coal province is limited largely to the State of Washington. Both California and Oregon have small fields within their borders, but the coal is generally of low rank or poor quality, and but little mining has been attempted. Washington, on the other hand, is fairly well supplied with coal in the western part, where it is most needed for the various industries that have been developed about Puget Sound. The coal-bearing rocks of Washington have been so greatly folded and contorted and then so deeply covered with glacial drift that it is possible to separate only a few of them into well-marked fields.

The coal fields of King County lie on the west side of the Cascade Mountains, extending from tidewater in the vicinity of Renton, 12 miles southeast of Seattle, to the foot of the mountains on the east. The thick cover of glacial drift and the almost impenetrable forest make coal prospecting laborious and difficult except near the principal streams, where these obstructions have been to some extent removed. The coal-bearing rocks are of eocene (tertiary) age and correspond in time of deposition with the lignite of the Dakotas, Montana, and Texas. In Washington, however, mountain-building forces have been so active in late tertiary time that many of the coals have been changed from lignite to subbituminous, bituminous, and even to anthracite. In general, the coals nearest the Cascade Mountains are the most altered. The mountain-building forces not only changed the character of the coal but also folded and broke the rocks in a most intricate manner, so that in places mining is difficult and expensive. The coal beds generally dip at considerable angles and are locally broken and displaced, so that it is difficult to follow a coal bed in mining. The old swamps in which the coal was deposited were apparently subject to many floods which washed mud and sand in from the surrounding higher lands. These materials settled to the bottom of the swamp, forming a shale or sandstone layer or parting in the coal bed, which today detracts greatly from its value, for the shale or sandstone must be removed before the coal can be marketed, and its removal is generally difficult and expensive. If the coal is put on the market after it is simply screened, it will contain a large percentage of ash, which makes it difficult to sell. The lump coal is generally so treated and reaches the market in fairly good condition, but in many places the fine coal is too dirty for marketing and must be washed before it can find purchasers. All coals contain more or less foreign material, in the form of partings or binders, but the coal of Washington includes more of such partings than the coal of many other parts of the United States.

The coals of King County are of subbituminous and bituminous rank in about equal proportions. The best coal in the county, to judge from the heating value of the pure coal, occurs along the mountain front from Snoqualmie on the north to Cumberland, a little south of Palmer Junction on the south, embracing a belt of country not more than three or four miles in width.

Many large mines are developed in this county, especially in the higher-rank coals near the mountain front, but some of the subbituminous coals, owing largely to their position on or near tidewater, are extensively mined, the coal finding a ready market as a domestic fuel.

The coals of Pierce County are the best in the state, but the known productive territory is very much smaller than that in King County. The coal at Wilkeson is the only coal in the state that has been extensively coked.

All the developed coal of Kittitas County is in the Roslyn field, which is a regular, shallow basin in the vicinity of Cle Elum, in the valley of Yakima River, on the east side of the Cascade Mountains. The basin is not complicated by minor folds and faults as are those on the west side of the mountains, and hence mining conditions are almost ideal. The coal is a hard, blocky coal of fairly uniform quality.

well adapted to shipping and handling. It has been extensively used by the Northern Pacific Railway for locomotive fuel. It is mined by slopes and drifts on the outcrop and by shafts in the middle of the basin.

Only a little coal occurs in Oregon, and that is of poor quality. Mining has been done in a commercial way only in the Coos Bay field, on the coast in the southern part of the state. The coal in this field is subbituminous and has done little more than to supply the small local demand. Although there is considerable coal in this field it is difficult to mine, and much of it lies below the waters of the bay. The field is not promising and probably never will be a large producer.

The best coal so far discovered in Oregon is in the Eden Ridge field, in the southern part of Coos County. The rocks are somewhat more disturbed here than in the vicinity of Coos Bay and the coal is of higher rank. It is bituminous, and some of it will coke, but the beds are full of shale partings which make the coal very dirty. The field has no railroad connection at the present time, and consequently no mining has been undertaken.

California, although rich in many other mineral resources, is singularly deficient in coal. At present the lack of coal is not felt, for the state has abundant supplies of fuel oil, but these supplies will sooner or later be consumed, and when the oil is exhausted the problem of obtaining coal will become vital. The only coal field of any prospective importance is that which lies in the Coast Ranges, in San Benito and Monterey counties. The most ambitious attempt to develop this field was made at Stone Canyon, Monterey County, where a bed of coal ranging from 10 to 14 feet in thickness was opened. The attempt was not successful, however, and the mine was abandoned. This coal is of the bituminous rank, and is the only coal of this rank in the state. It is very rich in bituminous matter and is in composition a cannel coal, though it has none of the physical properties of such a coal.

PRODUCTION AND ORIGINAL TONNAGE OF COAL IN UNITED STATES

Although the general description of a coal field is very important to one considering the development of mines, or to one contemplating an investment in mines or in mineral lands, there is another phase of the subject that is of equal if not greater importance to the political economist, and that is the quantity of coal still remaining in the ground, to which future generations may look for their supply of power and heat.

In undertaking to make an estimate of the original tonnage of coal in the ground, certain assumptions must be made as a foundation, and the results attained will depend largely upon these assumptions. The three principal assumptions are (1) minimum thickness of bed of the different ranks and grades of coal that can be mined, (2) maximum depth to which mining may be carried in the different ranks of coal, and (3) maximum percentage of ash that may be permitted in the various ranks of coal. As probably no two persons who have attempted to make estimates have made the same basic assumptions, so no two estimates agree as to the tonnage involved. This point is very important and is one that is usually lost sight of by the casual reader, who doubtlessly wonders why it is that experts disagree so widely in their estimates; whereas if he had analyzed the results a little more closely he might have found that the results were practically in accord.

Most engineers employed by private corporations base their estimates on the present practice of mining and preparing coal for the market, for the mining company must adopt this practice, and manifestly the company will not consider coal minable if it lies at a depth of 4,000 feet while plenty of coal of the same kind is available at a depth not exceeding 1,000 feet. Similarly, it will not consider minable a coal bed 20 inches thick while other beds of coal of the same kind of much greater thickness are still available. Also, to the operator of the present time, 15 per cent of ash in a coal may prevent its sale, and therefore its mining may be impracticable; whereas, if a washery were installed and plenty of water were available, 15 per cent of ash might be no bar to the mining and marketing of the coal. Most of the estimates so far made have been based on present mining conditions and practices, and hence they do not necessarily represent the tonnage that may be regarded as available 10 or even 5 years hence.

In attempting to make estimates of the original coal content of the fields of the United States, the Geological Survey decided that it would be a waste of time and money to attempt to make estimates based on present mining practice, for such estimates would be misleading in that they would not represent the total quantity of coal that undoubtedly would be made available in the future. With this point in mind, it was decided to attempt to esti-

TABLE I

Original and present quantity of coal in the United States, production of the mines in 1913 and 1914, and total production from the beginning of coal mining to the present time, in short tons

Province, region, or field.	Estimate of the original tonnage. Anthracite and semianthracite	Semibituminous coal	Bituminous coal	Subbituminous coal	Lignite.	Total coal of all ranks.	Coal below surface (from 3,000 to 6,000 feet).	Production in 1913.	Production in 1914.	Total production to end of 1914	Estimated supply within 3,000 feet of surface
Eastern province											
Anthracite region, Pennsylvania	21,000,000,000					21,000,000,000		91,524,922	90,821,507	2,537,517,517	17,194,000,000
Atlantic coast region	150,000,000	150,000,000	600,000,000			900,000,000				477,125	799,000,000
Appalachian region		48,487,200,000	502,411,400,000			550,898,600,000		330,737,079	284,813,462	5,238,735,592	543,039,000,000
	21,150,000,000	48,637,200,000	503,011,400,000			572,798,600,000		422,262,001	375,634,969	7,776,730,234	561,032,000,000
Interior province											
Northern and Eastern regions			321,990,800,000			321,990,800,000		88,533,841	83,412,935	1,439,863,711	319,830,000,000
Western and southwestern regions	400,000,000	1,226,300,000	206,282,200,000			207,908,500,000		26,694,136	25,291,303	575,038,328	208,044,000,000
	400,000,000	1,226,300,000	528,273,000,000			529,899,300,000		115,227,977	108,704,238	2,014,902,039	527,874,000,000
Gulf province					23,000,000,000	23,000,000,000		1,181,156	1,105,613	10,509,960	23,074,000,000
Northern Great Plains province											
Fort Union region, including Black Hills region			133,000,000	237,477,000,000	964,424,000,000	1,202,032,000,000		2,149,254	1,907,805	30,211,784	1,201,997,000,000
Small fields in Montana			2,000,000,000	7,073,400,000		9,073,400,000		1,704,355	1,561,824	24,907,259	9,036,000,000
Denver region and Durango (?) field			1,025,000,000	40,000,000,000		41,028,000,000		2,140,654	2,067,709	48,427,302	40,955,000,000
Raton Mesa region			42,392,000,000			42,392,000,000		8,191,362	7,590,810	133,390,905	42,192,000,000
			45,551,000,000	284,548,400,000	964,424,000,000	1,294,525,400,000		14,188,625	13,134,207	216,937,310	1,294,180,000,000
Rocky Mountain province											
[illegible]			47,200,000,000	3,496,000,000		3,543,200,000		20,091	20,000	5,441,863	3,535,000,000
[illegible]			466,800,000	4,736,700,000		5,115,000,000	12,010,000,000	1,600,721	1,612,941	13,633,150	5,291,000,000
[illegible]	57,000,000		173,138,000,000	491,500,000,000		665,040,000,000	196,720,000,000	5,780,091	5,377,736	101,339,000	665,178,000,000
[illegible]	400,000,000		162,718,000,000	[illegible]		168,218,000,000	243,440,000,000	4,092,415	3,723,542	57,317,183	167,682,000,000
[illegible]			[illegible]	2,830,000,000		2,846,000,000				782,000	2,870,000,000
[illegible]			4,000,000,000			1,000,000,000			2,000	2,000	4,000,000,000
[illegible]				150,000,000		156,000,000		109,037	68,146	2,459,413	152,000,000
[illegible]			[illegible]	181,500,000,000		196,000,000,000	14,000,000,000	1,000,000	874,132	17,574,000	196,011,000,000
[illegible]			[illegible]	20,000,000,000		21,000,000,000		117,970	137,361	4,148,414	21,800,000,000
[illegible]			[illegible]	200,000,000		200,000,000					200,000,000
	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	11,816,000	304,000,000	1,067,000,000,000
Pacific coast province											
[illegible]			[illegible]	[illegible]		63,854,000,000		[illegible]	3,064,820	67,524,200	63,753,000,000
[illegible]			[illegible]	[illegible]		1,063,000,000		[illegible]	[illegible]	[illegible]	1,032,000,000
			[illegible]	[illegible]		[illegible]		[illegible]	3,130,000	114,929,105	64,785,000,000
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	513,525,477	[illegible]	3,538,554,000,000

[illegible]

mate the total quantity of coal that ever would be mined in the United States, looking ahead 40, 50, or perhaps even 100 years. Of course, it is not contended that anyone living today can say positively what will be done 100 years hence, but an attempt was made to prepare such a forecast. In doing so the present mining practice throughout the world was considered, and the assumptions regarding maximum depth, minimum thickness, and maximum impurity were based upon present practice, but generally the limits now observed were exceeded because it is almost certain that the future will go far beyond the present operations, for in some places today the methods are far better than those that generally prevailed 20 or even 10 years ago.

As the deepest coal mines in the world in Belgium reach a depth of about 4,000 feet, and as shafts for copper and other metals have been sunk to depths below 5,000 feet, it was thought that future coal mining might be carried to a depth of 6,000 feet; but in order to meet various requirements two limits were set, one at a depth of 3,000 feet, for easily minable coal, and the other at a depth of 6,000 feet, a depth that represents what is now considered the ultimate limit of coal mining. Similarly, the minimum thickness of coal bed mined in the United States is about 15 inches, therefore 14 inches was taken as the minimum of high-rank coals for estimating the original tonnage in the several fields. The minimum thickness varies according to the rank of the coal [illegible] garded as the limit, but it is questionable whether it would not be better placed at 25 per cent.

Table I shows clearly certain features that are of the greatest interest regarding the distribution and amount of coal in the fields of the United States. It shows first that the great bulk of the coal in this country is low-rank bituminous, lignite, and subbituminous, named in the order of their abundance, and that the high-rank coals are relatively scarce. This is an important point in conservation, as it means that our best coal will be the first to be exhausted and that such exhaustion may occur in the not very distant future. It is also noticeable that the best steaming coal, the semibituminous, is limited practically to the two eastern provinces, and that the exhaustion of this coal will be a greater calamity to the country than the loss of all the anthracite, for coal of this kind has a greater efficiency and is adapted to more diverse uses than anthracite. Most people think of the eastern part of the United States as the greatest repository of coal in the country, and therefore they may be surprised to find that there are two areas in the West that contain a greater quantity. The greatest quantity of coal originally contained in any single area of continuous coal-bearing rocks is 1,202,032,000,000 tons, in the Fort Union region of Montana, Wyoming, and the Dakotas; the second is 665,660,600,000 tons, in the Green River region of Wyoming; and the third is 550,898,800,000 tons, in the Appalachian region of the East.

When the output of the mines is compared with the original quantity available it is seen that the great bulk of our coal is not necessarily coming from the areas that contain the greatest quantity, but from the areas that contain the best coal. This discrepancy becomes more startling when the production of the individual states is compared with their original coal resources.

Although the relative size of the contents of the coal fields may be a matter of some surprise, the really staggering fact presented in the table is the immense, really inconceivable total quantity of the coal.

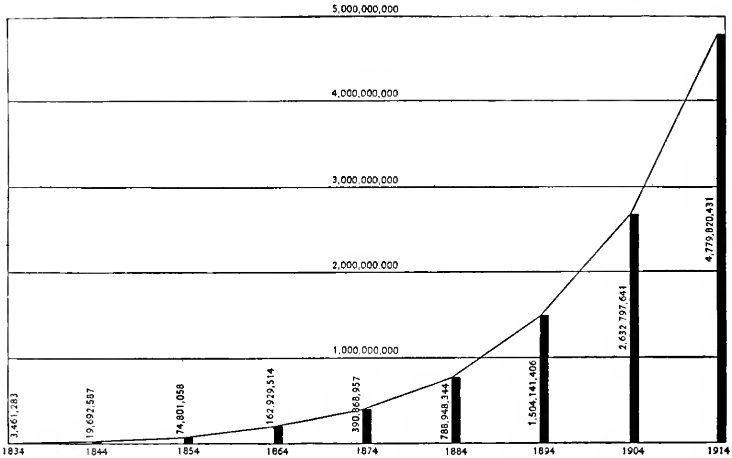


Fig. 2. Production of Coal in the United States by Decades from 1834 to 1914

There has been considerable speculation regarding the length of time the coal supplies would last, but here again there are so many unknown factors that any estimate partakes of the nature of a guess. Fig. 2 represents graphically the coal production in the United States by decades since 1834, and the increasing length of black shows conclusively that our coal production, or consumption, as it may well be called, is growing with great rapidity. In attempting, therefore, to calculate how long the available coal will last, it is manifestly incorrect to base the calculation on the present rate of production or consumption, or on the rate for the last decade, as the rate will continue to increase for a long time. If we assume that the rate of consumption will remain the same as it was in 1913, then, after allowance has been made for unpreventable waste in mining and marketing, there will be enough coal to last 4,000 years; but of course such an estimate is absurd, for the rate of 1913 will probably not be held in any single future year.

If the curve shown in Fig. 2 should be prolonged at its rapidly increasing rate, and if this acceleration should be continued until the coal is completely exhausted, the supply would probably not last 100 years. The true life of our coal fields probably lies between these two extremes, and the probability is that it will be nearer 100 than 4,000 years.

In 1908 Parker* attempted to extend the curve of production to what he conceived might be the possible maximum that would ever be reached in this country. His curve with slight modification to fit recently acquired data, is shown in Fig. 3. The past and the estimated future production were grouped by decades, beginning with 1835 and extending to the year 2055, when, according to his calculations, the maximum production of 23,000,000,000 short tons would be reached. As the quantity of coal mined in the decade ending with 1914 was 4,779,820,431 short tons, the maximum, according to Parker's figures, would be roughly five times the present production. After the maximum had been reached the production, owing to increased cost of mine haulage, of hoisting from deeper shafts, and of working thinner beds, would gradually decrease, but the decrease would probably be much less rapid than the increase up to the maximum According to the present estimates there is enough coal in the ground to permit production at this assumed maximum rate for more than 10 decades or 100 years.

The figures showing the production since 1908 prove that Parker's curve is too flat, for his estimate of the production in the decade ending in 1915 (4,528,000,000 tons†) is nearly equaled by the production of the nine years ending with 1914, which is 1,387,097,796 tons. Thus it seems that his estimated maximum production is too small or that the maximum will be reached before the year 2055 The estimate is probably too small and the maximum production will therefore probably be greater than 23,000,000,000 tons in a decade.

Although by every reasonable estimate the ultimate exhaustion of the coal reserves of the United States appears to be an event so far in the future that it need concern this generation but slightly the fact must be remembered that the bulk of the coal being mined today is the best in the country and that before long, perhaps within 50 years, much of the high-rank coal will be exhausted

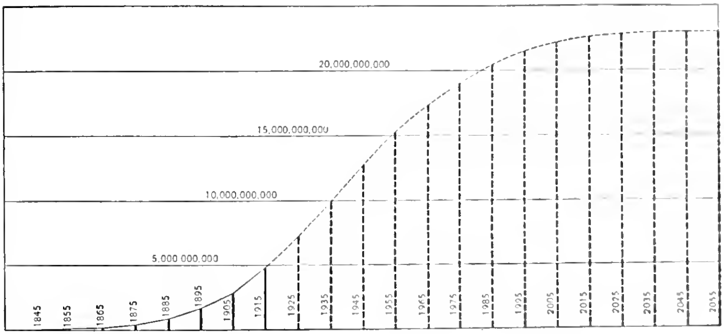


Fig. 3. Estimated Production of Coal in the United States to the Year 2055

* Parker, E. W., Past and Future Coal Production in the United States. Mines and Minerals, 1908, pp. 162–165.

† The production for the decade ending in 1915 was 4,918,717,283 tons.

A New Type of Mine Locomotive Controller

By L. W. Webb

Railway Equipment Department, General Electric Company

The type of mine locomotive controller described in this article was developed for service on large mine locomotives where the capacity of hand-operated drum controllers would be exceeded. The matter of space precludes the use of Type "M" control with magnetically operated contactors on any but the largest mine locomotives. The pneumatic hand-operated control for electric power equipments offers compactness, but as compressed air is not available on most mine locomotives the cam feature was adopted and the cam shaft arranged for manual operation. Diagrams are included showing the connections of the two-, three-, and four-motor controllers. This type of controller has proven so successful in operation that it is proposed to build it with seven cam units, for use on 50-ton, 600-volt switching locomotives.—Editor.

The demand for larger mine locomotives has taxed the capacity of hand-operated drum controllers beyond their limit. The high-pressure contacts, concentrated blowout and removable tips of the magnetically operated contactors make this type of control the next logical step to take care of the higher current. In some of the recent larger mine locomotives, the Type M control using magnetically operated contactors was adopted. However, as this control can only be used in locomotives where there is considerable room and as most mine locomotives are woefully lacking in this particular, there arose the problem of making a small compact high-capacity controller.

Fig. 1. Front View of Controller

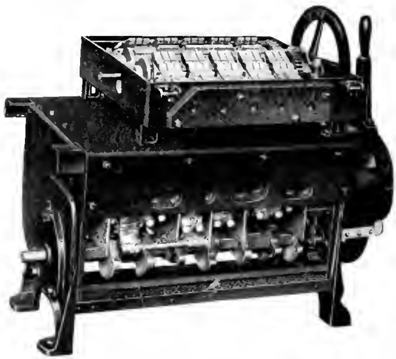


Fig. 2. Back View of Controller with Covers Removed

This compact feature is present in the pneumatic cam-operated control for electric car equipments; but as very few mine locomotives have air brakes, a pneumatically operated controller could not be used. It was, therefore, decided to use the compact cam units and to operate the cam shaft manually. This resulted in the development of the hand-operated cam controller shown in Fig. 1.

The controller consists of five or six cam units enclosed in a sheet-iron case with a cam shaft operated by a handle on the outside, and a separate reversing and series-parallel unit mounted on the top. This unit contains reversing and series paralleling cylinders and fingers of high capacity (see Fig. 2) which are mechanically interlocked with the main cam shaft so that no current is ever broken on them, the same as in drum controllers. All connections are made at the back as indicated in this illustration.

The controller gives six steps with the motors in either the series or the parallel connection. Table I gives the field covered by this type of controller. As the speed with three motors in series is too low to be of practical value, the three-motor controllers are arranged to give the parallel operation only. The four-motor controllers are for tandem locomotives; in other words, they are for controlling two two-motor locomotives from one operating position. The figure in the weight column for the four-motor controllers is the combined weight of the two locomotives. Fig. 4 shows the scheme of connections for one of the four-motor controllers. The connections for the two- and three-motor equipments are shown in Figs. 5 and 7.

In designing this controller, pneumatic cam-operated controller parts were used wherever feasible; and although there are a number of different forms, these are built up in the main by using common parts. For instance, the ratchet operating mechanism shown in Fig. 3 is so designed that it may be assembled on either end of the controller to suit the location in the locomotive. The mechanism is also arranged so that it may be used on controllers having as many as nine steps. Furthermore, the handle or grip part is adjustable so that the "off" position may be put at a convenient angle to suit the operator.

With only three sections of resistance and only five contact units, six steps are obtained. This is accomplished by different combinations of paralleling of the resistance sections. When the sixth unit is added, it is connected as a parallel circuit to the contacts which are closed in the running positions so that the capacity of the controller is doubled. This is shown in the schematic sketch, Fig. 8, in which contact No. 4 is the

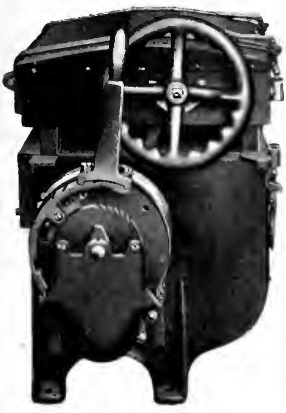


Fig. 3. End View of Controller Showing Ratchet Operating Mechanism

one which is added to double the capacity. The preceding features, as well as the added feature of having two different capacity units (550 and 750 amperes hourly rating) which will go in the same spacing, give this type of control a wide range in capacity.

The contacts have the same low maintenance as the Type M, and they have the added advantage of taking less space. In

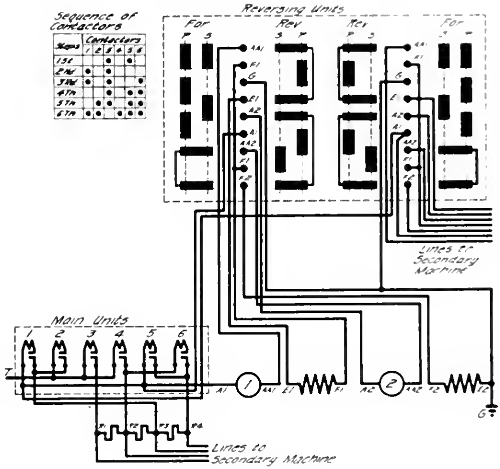


Fig. 4. Simplified Connections of Four-motor Controller

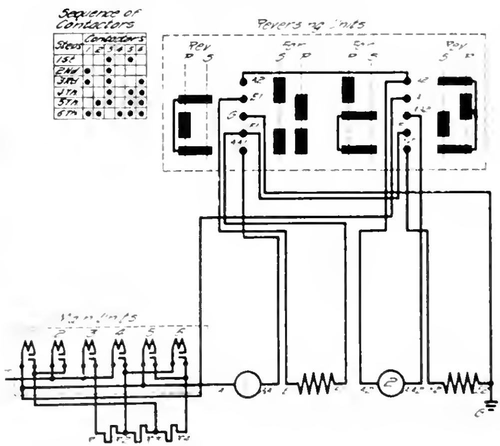


Fig. 5. Simplified Connections of Two-motor Controller

addition to removable tips, these units have small removable burning plates in the arc chutes, which may be easily slipped out and renewed without tools, see

Fig. 6. This illustration also indicates how the brake rod goes through between the main units and the reversing unit, which explains the reason for the space between the two. The arc chutes are all hinged together as one unit and swing down so that the contacts may be readily inspected.

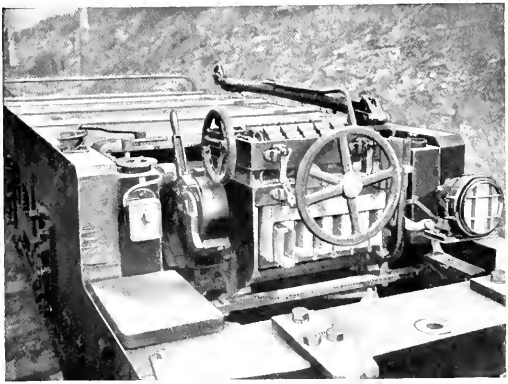


Fig. 6. Installation of Controller on Locomotive. Covers Removed

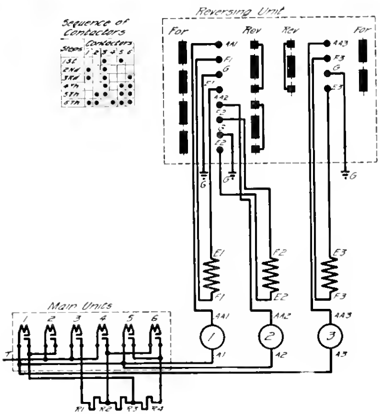


Fig. 7. Simplified Connections of Three-motor Controller

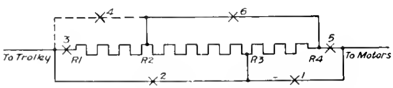


Fig. 8. Schematic Connection Diagram of Resistances

In order to get six steps the cam shaft must rotate 216 degrees. To rotate it directly would require too big a throw for the handle, and therefore a special one was designed with a four-to-one and also a one-and-a-half-to-one gear reduction. The travel to get the first point is approximately 26 degrees, and then a net movement of 9 degrees for each other point, as the action in going from point to point is back 15 degrees and then ahead 24, where a latch stops the handle on the point. The positive latch gives the same effect as an automotoneer as it requires the operator to stop on each point and then move back 15 degrees to release it. This latch may be taken off and the operator may then continue to pull the handle all the way on but will be using the high gear ratio entirely after the first point. This procedure is not recommended, however, as it makes it difficult to stop on a point. The ratcheting back enables the low-gear ratio to be used and still keep the total throw of the handle within the low-gear ratio limit.

The possibilities of this type of controller are so great that at present there is under consideration a new form containing seven units to be used on 50-ton, 600-volt switching locomotives.

TABLE I

Field Covered by Hand-operated Cam Controllers

Weight of Locomotive	Voltage	Number of Motors	Horse Power per Motor	Total Amps.	Controller
15	250	2	85	580	HC-7-A
15	500	2	85	302	HC-4-A
20	250	2	125	840	HC-7-A
20	500	2	125	420	HC-4-A
25	250	2	125	840	HC-7-A
25	500	2	125	420	HC-4-A
15	250	3	67	693	HC-5-A
15	500	3	67	347	HC-6-A
20	250	3	85	870	HC-5-A
20	500	3	85	453	HC-6-A
25	250	3	125	1260	HC-8-A
25	500	3	125	630	HC-5-A
35	250	3	125	1260	HC-8-A
35	500	3	125	630	HC-5-A
20 †	250	4	67	924	HC-1-A
20 †	500	4	67	462	HC-2-A
30 †	250	4	85	1160	HC-1-A *
30 †	500	4	85	604	HC-1-A
40 †	500	4	125	840	HC-1-A

* Use HC-1-A with large capacity units.
† Combined weight of two two-motor locomotives.

High-speed Circuit Breakers for Chicago, Milwaukee & St. Paul Electrification

By C. H. Hill

Switchboard Engineering Department, General Electric Company

Each of the 14 substations in the 440-mile electric zone of the C., M. & St. P. Rwy. is now equipped with high-speed circuit breakers, some of which have been in operation for over a year. This protective device is connected into the negative return circuit between the ground and the negative bus, and it is in parallel with a limiting resistance which becomes effective immediately the breaker opens. The article below describes the details of construction of this unusual equipment to which brief reference was made in our July issue.—Editor.

To protect the generating apparatus in the Chicago, Milwaukee and St. Paul substations from flashovers that result from short circuits near the stations, high-speed circuit breakers of unusual characteristics have been developed and placed in operation. This protective apparatus operates with sufficient speed to check the rise of current caused by a short circuit before damage can be done to the generating apparatus, the necessary speed being of the order of a few thousandths of a second.

In the high-speed circuit breaker which has proved itself successful in operation, the rate of acceleration of the main and the secondary contacts is approximately 8,000 feet per second, and the contacts are released in a time as short as 0.003 second or less from the beginning of a short circuit. The time from the beginning of the rise in current caused by a short circuit until the secondary contacts part has been shown to be of the order of 0.004 second. This rate of speed can better be appreciated when it is considered that the ordinary switchboard circuit breaker requires about 0.10 to 0.15 second. The high-speed breaker will therefore in effect foresee the rise in current which is caused by short-circuit, and will insert in the line sufficient resistance to limit this rise to a safe value.

Many railroads have adopted the practice of running the feeders to some distance out from the station before tapping them into the trolley wire in order to insert an amount of feeder as resistance between the substation and the tapping-in point. It was obvious that if a device could be developed to protect the generators from flashovers due to short circuits, its use would permit of the feeders being tapped directly into the trolley at the substation. With this method of connection, the feeder resistance will be unnecessary and its losses will be eliminated.

The amount of the loss caused by the insertion of this protective feeder resistance is quite considerable in many cases. On the Chicago, Milwaukee and St. Paul Railway preliminary calculations in connection with the electrification showed that quite an appreciable amount of power could be saved by the elimination of this additional feeder resistance. To accomplish this saving, work was started on the development of an air circuit breaker which would have such a high opening speed that the device could be used to insert resistance in the circuit quickly enough to prevent the short-circuit current from reaching a value that would cause the direct-current machinery to flash over. It was known that the circuit breaker would have to be designed to operate at a speed much higher than any previously attempted. Careful investigations demonstrated that the device must operate in a shorter time than is required for one commutator bar to pass from one brush stud to the next, i.e., less than one half cycle for that particular generator.

In each of the substations one of these high-speed breakers is connected into the negative return circuit between the ground and the negative bus. This location gives the maximum protection since the return circuit must pass through the limiting resistance in case of a flashover from positive to ground, for all the negative terminals, brush rigging, etc., are insulated for full generator voltage. Complete protection is assured by the high-speed circuit breaker being so interlocked with the regular switchboard air circuit breaker that the former must always be closed before the latter.

The fourteen 3000-volt, direct-current substations of the Chicago, Milwaukee & St. Paul Railway are equipped with this new type of circuit breaker and the first units installed have been in operation for nearly two years with very satisfactory results. Actual operation has demonstrated that, when protected by the high-speed circuit breaker, it is entirely practicable to operate direct-current substations with the feeders tapped into the

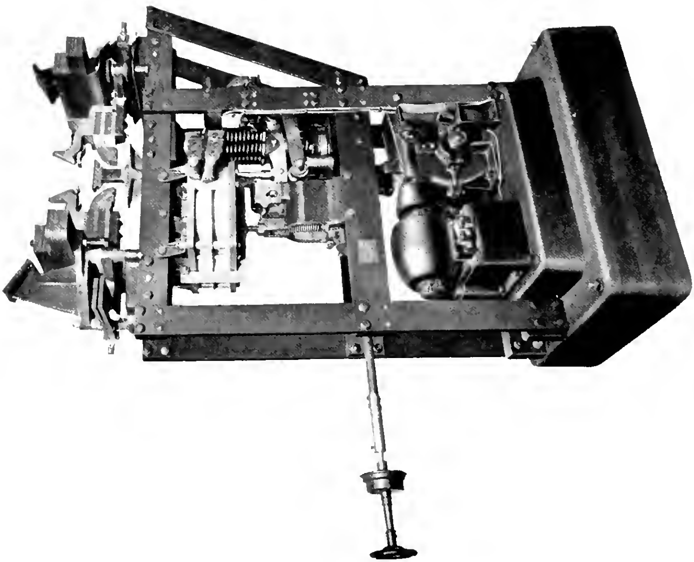


Fig. 1. View of High-speed Circuit Breakers with Arc Chute and Magnetic Blow-out Removed

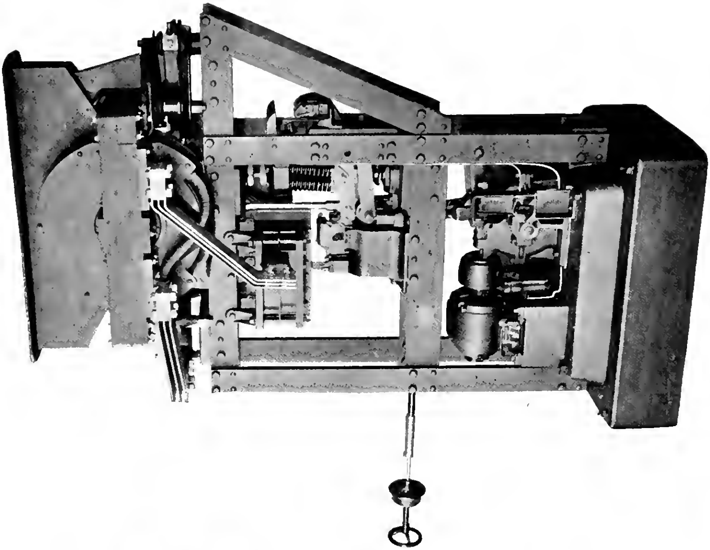


Fig. 2. Arc Chute and Magnetic Blow-out in Place

trolley system directly at the substation to eliminate the resistance losses occasioned by tapping in at some distance away, and that this is true even for a 3000-volt system which is the highest direct-current voltage used in railway work.

The high-speed circuit breakers installed are of the single-pole magnetic blowout type and are rated at 3600 volts, 3000 amperes direct-current. The circuit breaker and its mechanism are a self-contained unit mounted on a structural iron framework with a cast-iron base which, in turn, is mounted upon an insulated base to insulate the circuit breaker from the station floor. The circuit breaker can be closed either by hand at the breaker, or by a motor controlled from the station switchboard. When closed by hand, a ratchet mechanism is employed. The closing of the breaker by means of the motor is accomplished by a cam mechanism operated through gears.

The main contact brushes are stationary and are of the familiar laminated brush structure. The movable contact is a solid copper forging which is made as light as possible in order to reduce the mass to be moved. The secondary contacts are located above the main contacts and a very ingenious design has been employed to insure their breaking after the main contacts have broken, to eliminate any possibility of the current-carrying parts of the main contacts being burned. All of the contacts are located in a blowout chute of insulating material designed to withstand the burning incident to the arc. The blowout magnet is of large cross section and is made up of laminated iron. The usual shunt arrangement of blowout coils it was found would not give a sufficient speed of blowout, and therefore the blowout coils and trip coils of the breaker are connected in series in order that the blowout coils be excited at all times. The main and secondary contacts are mounted on a lever actuated by a group of compression springs that exert a force of about 8,000 pounds when the breaker is closed. A pressure of this magnitude is necessary in order to produce the rapid acceleration which high-speed operation requires.

The tripping is accomplished through a train of latches and levers actuated by a solenoid which has a specially laminated magnet frame and core to obtain a quick magnetic response to the short-circuit exciting current. The object in using a train of several latches is to enable the main latch to be moved through a distance of 1/8 inch by a solenoid which, in order to act in the time required, is able to move a distance of only about 0.001 inch and can exert a force of only about 200 pounds, while the main latch is subjected to a pressure of about 1000 pounds.

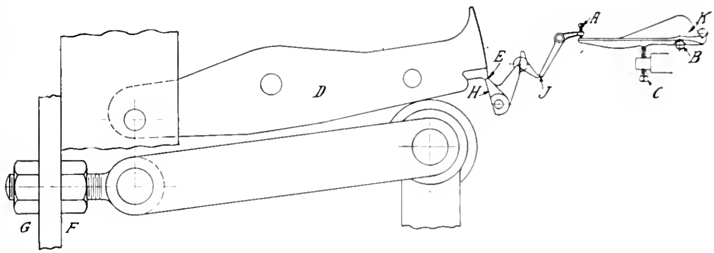


Fig. 3. Sketch showing Tripping Mechanism of High-speed Circuit Breaker

An adjustable tension spring, which directly opposes the pull of the solenoid, enables the circuit breaker to be calibrated in accordance with the varying number of generating units in the several stations.

The actual tripping takes place at the point *J* shown in Fig. 3. The solenoid applies its force at the point *B* that there may result a large and definite movement, which is later multiplied by the levers *A* and *K*. The latches *E* to *J* are specially formed to reduce the great pressure at *E* to such a value as can be handled by a small bearing surface at *J*.

When the breaker contacts open, the arc resistance becomes increasingly effective as the breaker completes its operation, and after the lapse of about 0.008 second or less from the beginning of the short circuit, the resistance has increased to such a value that no further rise of current can take place.

The high-speed circuit breaker described in the foregoing has demonstrated in actual service that it will protect generating apparatus from all short circuits, and that it will not only prevent damage to the brush rigging, commutator, etc., but will relieve the duty on the switchboard air circuit breakers.

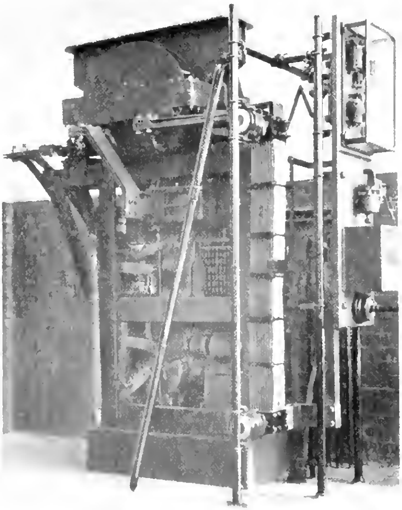


Fig. 4. High-speed Circuit Breaker Installed in Substation

The remarkably high operating speed of the circuit breaker and the resulting protection against damage to the equipment is ably shown by the oscillographic record in Fig. 5.

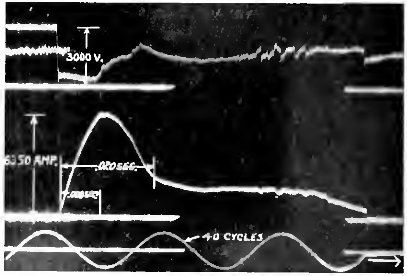


Fig. 5. Oscillogram showing Performance of Circuit Breaker

The maximum current rise is less than ten times normal and this is quickly reduced by the circuit breaker to well within the commutating capacity of the generator. Another especially good feature of this method of protection is that none of the effects of the direct-current short circuits is transmitted through the motor-generator set to the alternating current side, thereby preventing any effects of the direct-current short-circuit disturbances from reaching the alternating-current supply system.

Automobile Headlights and Glare-reducing Devices

By L. C. Porter

Illuminating Engineering Department Edison Lamp Works of General Electric Co., Harrison N. J.

In spite of all the study that has been given to the subject of automobile headlighting and the legislation that has been enacted to eliminate glaring lights from highways, there has not yet been developed a thoroughly satisfactory device or method to overcome this troublesome feature. However, much can be done to mitigate the evil through proper adjustment of lamps and the correct use of diffusing devices. In connection with this article, we would refer our readers to articles on automobile head lamps by Mr. W. F. Little, H. P. Gage, and Evan J. Edwards, published respectively in our issues of March, September, and November 1917.—Editor.

The rapidly increasing use of Mazda lamps for automobile headlighting, particularly with the higher candle-power lamps, has raised a general demand (in some states backed by legislation) for means of eliminating the glare from powerful headlamps. There are three methods of doing this in common use, viz.:

(1) By devices applied directly to the lamp bulb itself.

(2) By devices used in front of the reflector as cover glasses to the headlamp or in addition thereto (these devices may be subdivided into two classes, those diffusing the light, and those redirecting it into a general downward direction).

(3) By reducing the candle-power of the light source itself either by means of resistance or by the use of low candle-power auxiliary lamps.

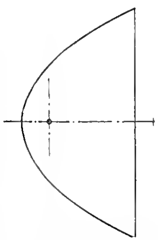


Fig. 1. Parabolic Reflector commonly used for automobile headlight service

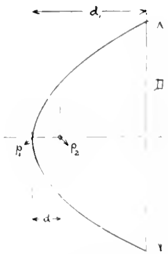


Fig. 2. Parabola plotted from the formula

$$d = \frac{\left(\frac{D}{2}\right)^2}{4\,d_1}$$

Most of the anti-glare devices work when properly adjusted and when the headlight itself is properly focused. However, conditions can easily occur, and as a matter of fact frequently do arise, where through improper adjustment the glare-reducing devices fail entirely, or even increase glare over what would occur without their use. This is often due to ignorance, on the part of the car driver, of the principles of a headlight and its proper adjustment. The following discussion is written in the hope that through education the most satisfactory service will be obtained from Mazda lamps whether used with or without accessory devices.

There are in general two means of projecting a beam of light: One, by the use of lenses, and the other by reflectors. For the purpose of this discussion only the latter method need

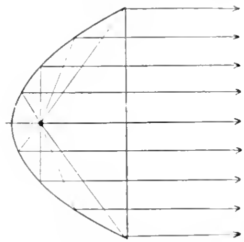


Fig. 3. Action of Light Rays originating from a theoretical point source located at the focal point of a parabolic reflector

be considered. Most automobile reflectors are so shaped that any ray of light originating at one particular point, called the focal point of the reflector, and striking the reflector, will be reflected parallel to the axis of the reflector. Such a reflector is called a paraboloid and is formed by rotating a parabolic curve, as in Fig. 1, around its axis.

The rays from a light source placed at the focal point of such a reflector will be projected in theoretically parallel paths, and the beam of light will be narrower than that resulting from any other position of the light source. The focal point is determined from the following relation:

The distance d (called the focal length) from the central point p_1 of the reflector (Fig. 2) to the focal point p_2 is equal to half the diameter D squared divided by four times the depth d_1 of the reflector, i.e.,

$$d = \frac{\left(\frac{D}{2}\right)^2}{4\,d_1}$$

Assuming that we have a true parabolic reflector and a true point source of light located at the focal point of the reflector, the light rays would be reflected as in Fig. 3, i.e., parallel to the axis of the reflector. The beam thus projected would remain of the same diameter as the reflector and would, neglecting absorption in the atmosphere, reach to infinity. An absolute point source of light is, however, a physical impossibility. All light sources must have some size, and the action of such a source is then as indicated in Fig. 4, i.e., each point of the reflector emits a cone of light, and hence the entire resultant beam is a cone. The spread of this cone depends largely upon the size of the light source—the larger the source the greater the spread of the beam, (Fig. 5).

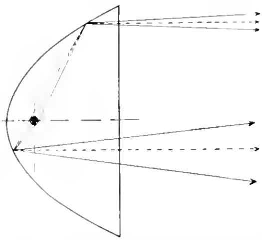


Fig. 4. Action of Light Rays originating from a light source having physical dimensions and located at the focal point of a parabolic reflector

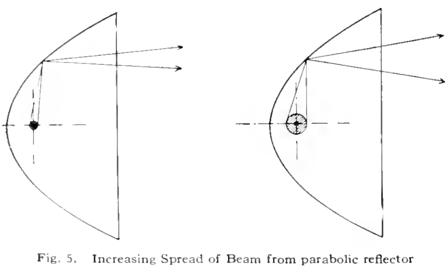


Fig. 5. Increasing Spread of Beam from parabolic reflector due to increasing size of light source

Now, a very narrow beam would be unsatisfactory for automobile headlight service. Two narrow shafts of light in front of the car would give very poor road illumination. On the other hand, too great a spread would mean greatly reduced intensity and penetration of the beam, because it is obvious that with a definite amount of light spread out over a large area, the intensity thereon cannot be so high as though the light were all confined to a small area.

The filaments of Mazda headlight lamps have been carefully designed to occupy such a space as to give the proper spread for good road illumination, and at the same time to be sufficiently concentrated to obtain a powerful, far-reaching beam, *provided* they are properly located at the focal point of the reflector.

Let us see what happens if the filament is not properly located with respect to the focal point of the reflector. Let us assume that it is ahead of the focal point. One of the laws of reflection of light from polished surfaces, such as headlight reflectors, is that the angle of incidence is equal to the angle of reflection, (Fig. 6). The angle of incidence is the angle at which the ray of light strikes the reflecting surface. It is formed by the ray of light R and the normal N to the surface, i.e., angle α. The angle between the normal N and the ray of light after reflection R is the angle of reflection. Angle α is equal to angle B; hence with the light source ahead of the focal point, the condition would be as in Fig. 7. The upper half of the reflector would project light down onto the road, while the lower half would project it up into people's eyes. Suppose, on the other hand, that the light source were back of the focus; the condition would then be reversed, as in Fig. 8, and in either case the greater the distance between the light source and the focal point, the greater will be the spread of the projected beam. It may even become so great as to cause a dark spot to appear in the center.

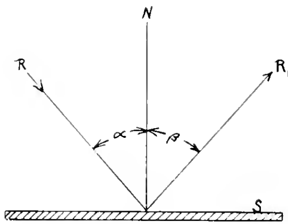


Fig. 6. The Law of Reflection from a polished surface, namely, the angle of incidence is equal to the angle of reflection

S, Reflecting Surface; N, Normal to S;
R, Incident Ray of Light; R_1, Reflected Ray;
α, Angle of Incidence; β, Angle of Reflection

The proper location of the light source, either ahead of or behind the focal point, then becomes of vital importance when employing such glare-reducing means as painting part of the cover glass of the headlamps or half of the bulb itself, or cutting off the light therefrom by means of attached reflecting devices, or the use of prismatic cover glasses so designed that one half deflects the light rays downward and the other half spreads them sideways. From Figs. 7 and 8 it is evident that the portion of the cover glass to be opaqued, in order to prevent upward rays of light, should be the lower part if the light source is ahead of the focal point; also, the lower half of the bulb should be screened. If the lamp is behind the focus the upper part of the cover glass or bulb should be screened.

glare-reducing device, onto a flat surface perpendicular to the axis of the beam, at a distance of not less than 25 feet. The lamps should then be adjusted in the reflector, by means of adjusting screws or other devices now furnished on all good headlights, until the smallest spots of light obtainable are thrown on the distant surface. The lamps will then be at the focal points of the reflectors. The appearance of the spot of light projected by each headlamp should in this case be approximately as shown in Fig. 10-A. If the lamp is too far ahead of or behind the focus, the spot should appear about as in Fig. 10-B. With the lamp in focus, careful measurements should be made to determine whether the centers of these spots of light are any higher than the centers of the headlamps themselves. If they are, the headlamps should be bent

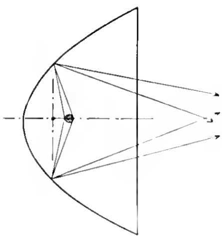


Fig. 7. Action of Light Rays originating from a source located ahead of the focal point in a parabolic reflector

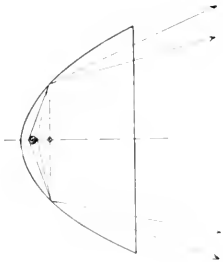


Fig. 8. Action of Light Rays originating from a source located behind the focal point of a parabolic reflector

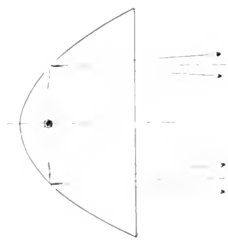


Fig. 9. Action of Light Rays originating from a source located at the focal point of a parabolic reflector

down until the center of the beam comes slightly below the horizontal.

If the light source is exactly at the focal point an equal amount of light is projected both upward and downward by each half of the reflector (Fig. 9). In this case the only effect of the means mentioned above of reducing glare is to reduce somewhat the intensity, and hence the effectiveness, of the projected beam, but without eliminating glare.

It frequently happens that headlight brackets become bent in such a manner that the reflector is tilted up and the beam projected above the horizontal, regardless of the focus of the lamp.

The motorist who uses any of these means to reduce glare should make a very careful study and adjustment of the headlamps. The adjustment can best be accomplished by standing the car on a level roadway and projecting the headlight beams, without any

Next, the lamp should be moved *slightly* forward or backward, to bring it about $\frac{1}{32}$ of an inch in front of or behind the focal point, (Fig. 10-C), and the glare-reducing device applied to the lower part of the bulb or cover glass if the lamp is moved forward, or to the upper part if the lamp is moved backward. The appearance of the spot should then be somewhat as shown in Fig. 10-D. As a general practice it is preferable to locate the lamp behind the focal point because there it is set deeper in the reflector and a larger percentage of the emitted light flux is utilized. Also, placing the glare-reducing device on the upper half prevents the direct light from the filament, which is not caught by the reflector, from being emitted upward, while that emitted downward will fall on the road in the immediate foreground of the car. However, if opal dipping, silvering, or other forms of painting, or even external reflectors, are applied directly to the upper part of the lamp bulb, the intense heat rising directly from the filament of the Mazda C lamp is liable to cause rapid deterioration, and the reflecting heat may shorten the life of the lamp. For this reason we do not recommend that any glare-reducing means be applied directly to the bulb itself.

There are on the market several glare-reducing devices consisting of offset reflectors or reflectors having different focal points of these devices is that they will take the rays of light coming from the reflector and bend them down to such an extent as to keep them below the horizontal, and at the same time spread them somewhat so as to give good side illumination. Most of these devices are designed to operate with the light source exactly in focus; hence if such a device is used the motorist should carefully locate his light source at the exact focal point of the reflector, in the manner described above, before applying the glare-reducing device (Fig. 11). If the lamp is not at the focal point, those rays projected upward by the reflector, as in Figs. 7 and 8, may rise

A C B D E

Fig. 10

A, Spot of light at distance of about 25 feet from head lamp with lamp at focus of reflector.
B, Lamp too far ahead or behind the focus.
C, Lamp slightly forward or back of focus.
D, Same as C, but with glare reducing device in place.
E, Head lamp equipped with prismatic cover glasses, with lamp at focal point of reflector.

for the upper and lower halves or different curvatures therefor The same general principles outlined above apply to this class of glare-reducing devices, careful focusing being necessary. The lamps should be so adjusted that the major part of the projected light very evidently falls below the horizontal when the headlamps are directed at a vertical surface, as described above. The appearance of the spot should be similar to that of Fig. 10-D.

There is a widely distributed class of glare-reducing devices known as prismatic cover glasses, of one type or another. The theory at such a steep angle that while they are bent somewhat by the glare-reducing device they will still emerge above the horizontal, and the glare-reducing device then becomes only partially effective (Fig. 12). Fig. 10-E shows the appearance of the spot when the lamp is properly focused and Fig. 10-F when the lamp is out of focus.

Another class of glare-reducing device is found in the various diffusing designs. The theory of such devices, which generally take the form of cover glasses composed of many small lenses, corrugations, frosted glass, etc., is that by reducing the intensity of the light and spreading it out over a greater area, glare will be reduced and a very pleasant driving light obtained. The trouble with this class of device is that in order to obtain light at a considerable distance ahead of the car, the motorist must resort to very powerful headlamp bulbs, and under these conditions there still remains dangerous and annoying glare, and over a much wider angle than is the case with other types of anti-glare devices. With the diffusing device the focus of the bulb has little effect on its glare-reducing property, though it is advantageous to have the lamp exactly in focus, as this will assist in obtaining maximum penetration of the beam by concentrating the strongest light at the center. The general appearance of the spot from a typical diffusing device is shown in Fig. 10-G.

How powerful a headlight it is advisable to use is a question which many motorists ask. It is a question to which no definite answer can be given, and therefore a little explanation of the variables entering into it may be of assistance in making a choice.

The headlamps serve two purposes, viz.: first, to act as a warning of the approach of the motor car, and second to enable the driver to see his way and to discern obstacles in his path in sufficient time to avoid them. For the sake of simplicity, let us assume the obstacle to be a man standing in the road. How far will the automobile headlights "pick up" the man? This depends upon three things:

(1) The power of the headlight.

(2) The contrast between the object and its background.

(3) The condition of the atmosphere.

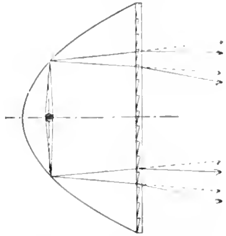


Fig. 11. Action of Light Rays originating from a source located at the focal point of a parabolic reflector equipped with a prismatic cover glass

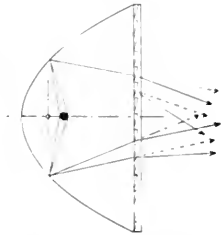
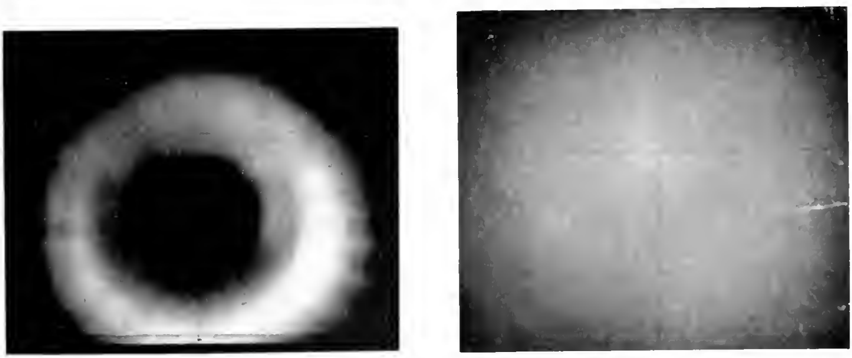


Fig. 12. Action of Light Rays originating from a source ahead of the focal point of a parabolic reflector equipped with a prismatic cover glass

Let us assume the atmosphere to be reasonably clear. If the object is dressed in black and viewed against a black ground, such as an asphalt road, there is little contrast between the two. If the object is dressed in white, the contrast between it and the background would be great, and consequently a much less powerful headlight would "pick up" the object at the same distance. Besides



F G

Fig. 10 Cont'd

F, Same as F, but with lamp [illegible]
G, Illumination from head lamp fitted [illegible] diffusing glass

the contrast effect there is another condition to be considered. We see objects either in silhouette against a lighted background or else by reason of the light reflected from the object back to our eyes. White reflects much more light than black. The amount

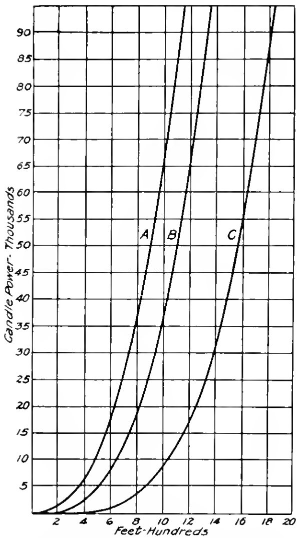


Fig. 13. Curve showing beam candle-power necessary to "pick up" a man at various distances. A, man dressed in light clothes; B, medium shade clothes; C, dark clothes

of light reflected by various colors increases with increasing lightness of hue; for example, yellow reflects more light than brown, and brown more than dark green, etc., white and black being the two extremes. We see therefore, that the worst condition is a dark object on a dark, unlighted street requiring the most powerful headlight. Unfortunately, glare is also most severe under these conditions. In broad daylight one can look directly into an automobile headlight without a great deal of discomfort, whereas such a procedure at night would be exceedingly trying. This is because, owing to the brightness of the surroundings during the day, the iris or diaphragm of the eye is stopped down to a very small opening, thus reducing the amount of light entering the eye; whereas, at night the eye is fully expanded ready to admit the maximum amount of light. The brightly lighted city street is a condition part way between these two extremes.

Many tests have been made to determine how far beams of different candle-power will "pick up" objects. One of the large eastern railroads worked this out very carefully, at a time when they were making a study of how to meet the interstate commerce ruling requiring locomotives to carry headlights of sufficient power to enable an engineer to "pick up" a man at 800 feet. The data they obtained for men dressed in light, medium, and dark clothes and viewed against the average railroad roadbed, which may be considered dark, are shown by the curves in Fig. 13.

The beam candle-powers of typical automobile headlamps 10 in. in diameter and equipped with 21 candle-power Mazda C headlight lamps are in the neighborhood of 50,000. Equipped with glare-reducing devices this figure will be lowered from 25 to 90 per cent, the latter being for the diffusing type of anti-glare device.

By moving the filament out of focus in steps of $\frac{1}{16}$ of an inch at a time, the beam candle-power of a headlight was found to drop off as follows:

Filament at Focus	Beam c-p. 100 per cent
Filament 1/16 in. from focus	Beam c-p. 31 per cent
Filament 2/16 in. from focus	Beam c-p. 18 per cent
Filament 3/16 in. from focus	Beam c-p. 8 per cent
Filament 4/16 in. from focus	Beam c-p. 4 per cent

The effect on the pick-up distance can be taken from Fig. 13, which again illustrates the importance of proper focusing.

Simple Methods for Solving Floodlighting Problems

By H. E. Butler

Illuminating Engineering Laboratory, General Electric Company

Floodlighting is practically a new branch of illumination and, as a consequence, the methods for its calculation which, up to this time, have been offered the laymen have been too much of the highly technical laboratory type. Through the efforts of illuminating engineers, the art is becoming so standardized as to reduce to a very simple procedure the calculations to be made for commercial purposes. The author of the following article describes these methods and their application to both high-intensity and low-intensity illumination with floodlights.—Editor.

The practical electrician or commercial man who deals with floodlighting problems is seldom familiar with the theoretical methods for determining the required equipment and its proper location. Simple methods for solving this class of problems, with which the practical man is constantly dealing, are explained in this article.

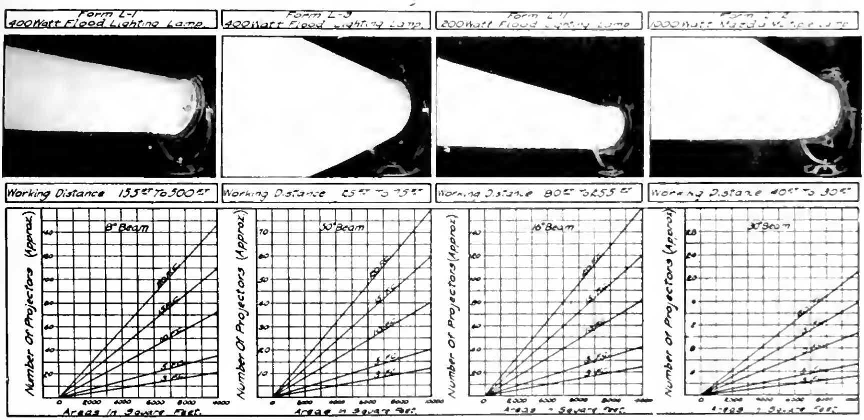


Fig. 1. General data on floodlighting projectors for high-intensity illumination. Working distances are given for convenience in selecting the proper floodlighting projector. Local conditions may necessitate a change in some cases

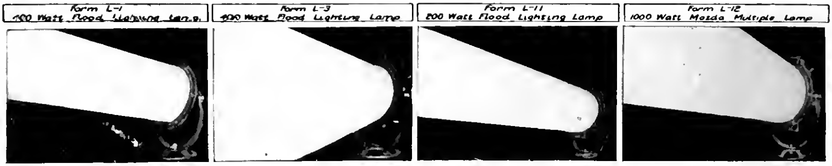
TABLE OF INTENSITIES FOR FLOODLIGHTING

	Character of Surroundings		
	White Way	Residences	Parks
Dark colored buildings	20 f.c.	15 f.-c.	[illegible]
Medium colored buildings	15 f.c.	10 f.c.	[illegible]
Light colored buildings...	10 f.c.	5 f.-c.	[illegible]

In using this chart the angle between axis of beam and surface [illegible] lighted must not be less than 70 deg.

Floodlighting is a comparatively new type of illumination but its future is a very promising one, and the range of its applications is continually broadening. Already it has been successfully used as an illuminant for facilitating night activities in connection with arsenals, manufacturing plants, grain elevators, freight terminals, patrol duty, quarries, piers, shipyards, docks, toboggan slides, race tracks, athletic grounds, rifle ranges, and gun clubs. Also, it has been used for utilitarian or decorative effects in connection with the illumination of prison walls, clock towers, street squares, building fronts, flags, statues, theater fronts, outside theatricals, fountains, billboards, signs, advertising banners, etc. The night views in this article illustrate how effectively floodlighting units can be used.

From the foregoing number of applications it is evident that floodlighting will be a permanent addition to the art of illumination,



Distance from Projector—Feet	Diameters, Areas and Intensities for One Unit Only											
	8° Beam			50° Beam			16° Beam			30° Beam		
	Diameter Feet	Area Square Feet	Average Foot Candles	Diameter Feet	Area Square Feet	Average Foot Candles	Diameter Feet	Area Square Feet	Average Foot Candles	Diameter Feet	Area Square Feet	Average Foot Candles
25	3.5	9.6	148.000	22.3	389	6.750	7	38.5	33.800	13.4	141	67.100
50	7.0	38.5	37.000	44.6	1556	1.680	14	154.0	8.430	26.8	564	16.800
100	14.0	154.0	9.250	93.0	6793	0.385	28	616.0	2.110	54.0	2290	4.140
200	28.0	616.0	2.310	186.0	27172	0.096	56	2463.0	0.527	108.0	9161	1.030
400	56.0	2463.0	0.580	372.0	108687	0.024	112	9852.0	0.132	216.0	36644	0.258
600	84.0	5542.0	0.257	558.0	244545	0.011	168	22167.0	0.059	324.0	82448	0.115
800	112.0	9852.0	0.145	744.0	434746	0.006	224	39408.0	0.033	432.0	146574	0.065
1000	140.0	15394.0	0.093	930.0	679292	0.004	280	61575.0	0.021	540.0	229022	0.041

Fig. 2. General Data on Floodlighting Projectors for Low-intensity Illumination

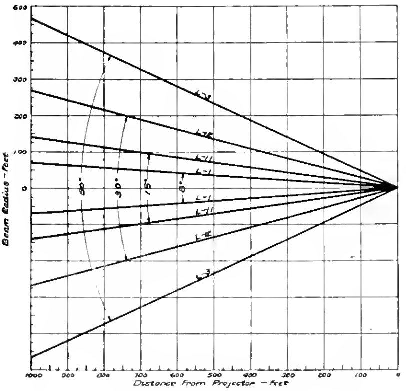


Fig. 2a. Chart of Beam Spread for Different Projectors

and that there will always be a great demand for floodlighting units. It should be borne in mind, however, that the floodlight projector is not suitable for the general illumination of interiors because the distribution is too strongly directional and creates sharp shadows. The beam spread of commercial floodlighting units ranges from 8 deg. to approximately 50 deg. and the type chosen will depend entirely on local conditions.

When studying local conditions, three important factors must be carefully considered before specific conclusions can be deduced as to the type of unit best suited to the purpose.

(1) The working distance, i.e., the distance from the projectors to the surface to be illuminated.

(2) The character of the surroundings, i.e., whether the area to be lighted is located along a "white way," residential section, park, or in a place where there is no stray light.

(3) The color of the building surfaces, i.e., whether the surface to be lighted is dark, medium, or light.

The first factor plays an important part in determining the most suitable type of projector, and the two latter factors play a very important part in deciding the foot-candle intensity required for each installation.

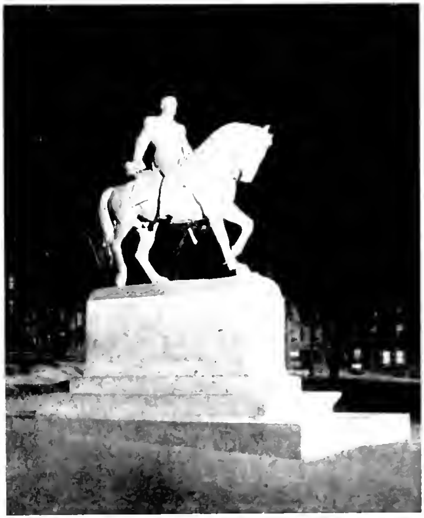
Especial emphasis is to be laid upon the fact that, when selecting floodlighting projectors, it is necessary to give particular consideration to the area that is to be illuminated, to the beam spread, and to the distance the light or beam is to be projected. For example, the use of a wide-beam unit for a small area, or a narrow-beam unit for a large area, will give unsatisfactory results.

The data furnished in Figs. 1, 2 and 2a will facilitate the solving of floodlighting problems and the estimating of the amount of material necessary.

As a guide for the comparison of intensity values in this article, it will be well to remember that full moonlight corresponds to approximately 0.025 foot-candles.

Fig. 1 is to be referred to for high intensity floodlighting, and Figs. 2 and 2a for low intensity work. In Fig. 1 are indicated the following data: the type of floodlighting units, the size of lamp employed for each type of unit, the photograph of the unit and the beam spread, the working distance for each type of projector, curves showing the number of units required to illuminate areas at different

Patriotic Posters, etc., are made Effective at Night by Floodlighting



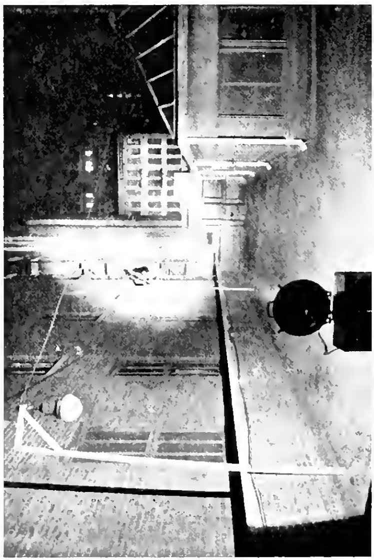
Statuary is Beautified by Floodlighting

High Towers, when Illuminated, Become Beacons at Night

Portable Floodlighting Outfits are Useful in Times of Emergency


Floodlights Facilitate Breaking Up and Shifting Long Freight Trains at Night


Cargoes at Docks can be Loaded and Unloaded at Night


Protective Floodlighting on Roofs of Buildings


Adequate Illumination Speeds Up Ship Building at Night

Piers, Terraces, Raised Walks, etc., when Illuminated can be Used at Night

Floodlighting Extends the Usefulness of Playgrounds into the Evening

Public Buildings may be Made Prominent and Beautiful at Night

Illumination Enables Advertising to be Carried on 24 Hours a Day intensities, and a table of intensities to cover conditions when the surroundings are those of white way, residence sections, or parks, and when building surfaces are dark, medium, or light.

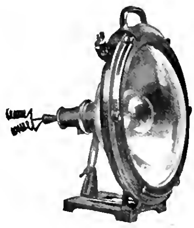
To show the method of applying the data of Fig. 1, a high intensity floodlighting problem will be figured out. Consider the proposition of floodlighting an area of 6,000 sq. ft. located in a white way section. The local conditions are such that the units will have to be installed 130 feet from the illuminated surface. The color of building surface is dark. What type of floodlighting unit should be used and also what is the intensity and the number of units required? The first three factors necessary to solve this problem are:

(1) The working distance is 130 feet, i.e., the floodlighting units are to be located 130 feet away from the illuminated surface.

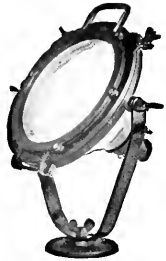
(2) The area or surface to be floodlighted is located in a white way section.

(3) The building surface to be illuminated is of dark finish.

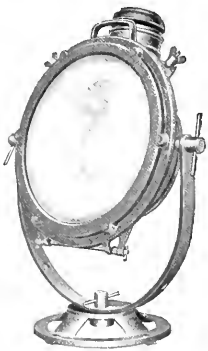
Reference to the chart in Fig. 1 shows that, for a working distance of 130 feet, the L-12 floodlighting unit will fill the requirements. By referring to the table of intensities in Fig. 1, it is noted that the intensity required for dark colored surfaces in white way sections is 20 foot-candles. Reference can now be made to the curves for the L-12 projector in Fig. 1, from which can be determined the number of L-12 units required to illuminate the various areas to intensities of 3, 5, 10, 15 and 20 foot-candles. Follow up the vertical line from 6000 sq. ft. until it crosses the 20 foot-candle curve, then go horizontally to the left which reveals that approximately thirteen L-12 floodlighting projectors are required for this installation.



Form L1



Form L11



Form L12

Form L3

Floodlighting Projectors

No additional example will be necessary as all high intensity floodlighting problems are solved in a similar manner. It should be borne in mind, however, that in using the data given in Fig. 1 the angle between the axis of the beam and the surface lighted must not be less than 70 deg.

In Fig. 2, photographs of the lighting units are again given to identify them readily, to indicate the size of the lamps for each type of projector and also the beam spread. In Fig. 2 there are included tables indicating diameters, areas, and intensities of beams for each type of unit. Curves are given in Fig. 2a to show graphically the relation of the beam radius in feet for distances from 25 to 1000 feet from the projector. These curves make it possible to obtain the intermediate points not tabulated in the table.

To show the method of applying the data of Fig. 2, a typical problem will be figured out. Consider that an area of approximately 15,000 sq. ft. is to be illuminated and the units are to be installed 1000 feet from the illuminated area, and the surrounding conditions are such that no other source of light is present.

From the data in Table I, which are obtained from data given in Fig. 2, it will be seen that the L-1 beam will cover an area of 15,000 sq. ft. with approximately four times moonlight intensity of illumination, while the other types cover greater areas with less intensity. A consideration of the data on the L-12 unit shows that should this unit be employed in this case, the resulting beam would cover an area fourteen times greater than necessary, which would consequently lower the illumination approximately 50 per cent. On the other hand, should the proposition call for the illumination of an area of 230,000 sq. ft. at a distance of 1000 feet, the L-12 type unit

TABLE I

BASED ON DISTANCE OF 1000 FEET FROM PROJECTOR

	Form L-1	Form L-3	Form L-11	Form L-12
Beam spread, deg	8	50	16	30
Beam diameter, ft.	140	930	280	540
Beam area, sq. ft..	15,394	679,292	61,575	229,022
Average, foot-candles	0.093	0.004	0.021	0.041

would be the logical one to use. If the L-3 type unit were used in the particular installation under consideration, it would illuminate an area forty-five times greater than necessary and would consequently lower the illumination to approximately 4 per cent. These comparisons point out the fact that the illuminated surface should be carefully considered before choosing the type of unit for each problem. It should be remembered that the average foot-candle intensities given in Fig. 2 indicate values obtained from one unit only. To improve these intensities, additional units should be installed.

Old Glory in the Beam of a G E Floodlight

The Standard Outdoor Substation

By J. T. Bronson

Switchboard Sales Department, General Electric Company

The development of satisfactory switching and transformer equipment for outdoor installation along high tension transmission lines has been a big factor in extending the service of electric power companies. Through the use of this apparatus the need of special buildings for shelter has been dispensed with, and service can be furnished at a profit in many cases where previously the interest on the investment for buildings, equipment, etc., and the cost of attendance would have shown a loss. In this article are outlined the requirements of outdoor switching apparatus, and the types and equipment of outdoor substations. Curves are given to show the comparative cost per kv-a. of outdoor substations of various size.—Editor.

The standard outdoor substation has been developed to meet the growing demand for electrical energy by consumers located along the right-of-way of high-tension transmission lines. In some cases these lines were originally intended to supply only distant towns where the load was concentrated and large enough to warrant the expense of running lines and installing substations. In more recent cases, transmission lines have been built for the express purpose of supplying not only concentrated loads but also smaller isolated consumers situated along or near the rights-of-way. The latter distribution arrangement has been made possible only by the development of outdoor high-tension switching apparatus which from the commercial point of view is low in first cost and from the engineering standpoint is of sufficiently high quality to meet the following requirements:

(1) It should be weatherproof.

(2) It should be capable of being operated without causing disturbances on the main transmission line.

(3) It should be of substantial and lasting construction.

(4) It should have low maintenance cost and should not require an attendant.

(5) It should be capable of being safely operated by persons unskilled in the use of electricity.

There are numerous applications of the standard outdoor substation, and operating companies are realizing more and more that its more extended use will open to them a profitable source of revenue. Outdoor substations also make readily possible the interconnections between central station companies and the linking up of various sources of energy and supply. These latter applications should be given immediate attention for the war is daily imposing severe demands for economy and efficiency, and the conservation of fuel, building material, labor, and electrical apparatus.

Types of Standard Outdoor Substations

There are several distinct types of the standard outdoor substation, these differing mostly in accordance with the size and nature of the load, the initial cost, and the central-station requirements. The smaller, low-capacity types are wood-pole mounted.

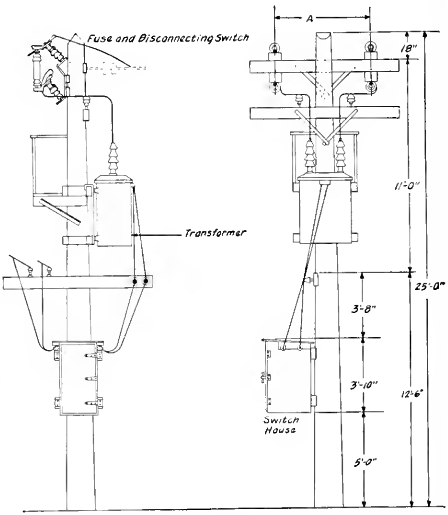


Fig. 1. Standard Outdoor Substation, pole-mounted, single-phase, 45,000 volts maximum high tension, 2300 volts maximum low tension, 75 kv-a. maximum

The larger, high-capacity types are steel-tower mounted. Some types which are in general use and are mounted on wood poles are described and illustrated in the following:

The substation shown in Fig. 1 supplies 75 kv-a. (max.) single-phase at 45000 volts maximum high tension and 2300 volts, maximum low tension. It is comprised of:

One single-phase, step-down transformer.
One low-tension switch and meter house.

Two single-pole combined fuse and disconnecting switches operated by a fuse hook.

The substation shown in Fig. 2 supplies 150 kv-a. (max.) three-phase at 45000 volts maximum high tension and 2300 volts maximum low tension. It is comprised of:

Three single-phase, step-down transformers.

One low-tension switch and meter house.

One triple-pole, single-throw combined disconnecting switch and fuse with direct hand-operating mechanism.

Types of other substations which are in general use and are mounted on steel-tower framework are described and illustrated in the following.

Figs. 3 and 4 show substations having the transformers mounted on a platform above the ground. These supply 150 kv-a. (max.) three-phase at 45000 volts maximum high tension and 2300 volts maximum low tension. They are comprised of:

One steel switching tower. (Fig. 3 painted) (Fig. 4 hot galvanized).

Three single-phase, step-down transformers.

One low-tension, single-throw combined disconnecting switch, fuse, and choke coil, with direct remote control hand-operating mechanism.

One aluminum lightning arrester.

Figs. 5 and 6 show substations having the transformers mounted on the ground level underneath the tower. These supply 1500 kv-a. (max.) three-phase at 45000 volts maximum high tension and 15000 volts maximum low tension. They are comprised of:

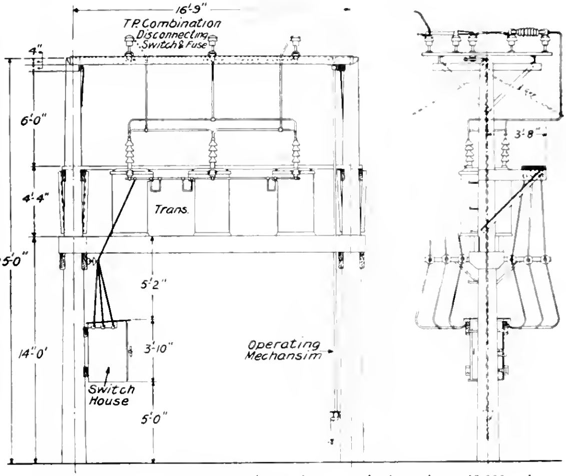


Fig. 2. Standard Outdoor Substation, pole-mounted, three-phase, 45,000 volts maximum high tension, 2300 volts maximum low tension, 150 kv-a. maximum

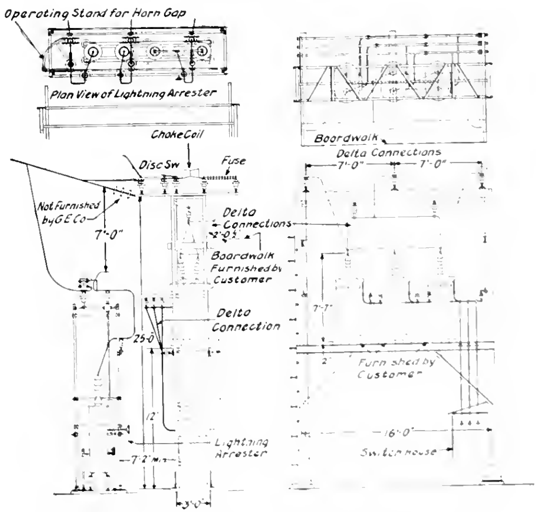


Fig. 3. Standard Outdoor Substation, steel structure mounted, three phase, 45,000 volts maximum high tension, 2300 volts maximum low tension, 150 kv-a. maximum

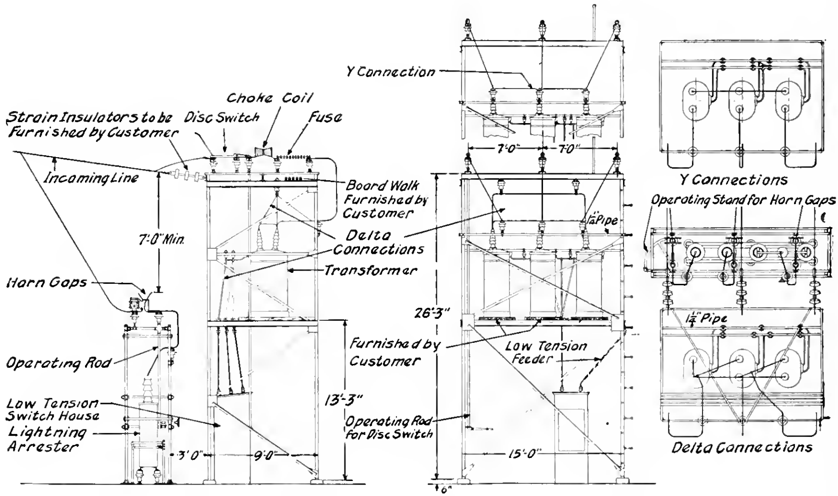


Fig. 4. Standard Outdoor Substation, steel structure mounted, three-phase, 45,000 volts maximum high tension, 2300 volts maximum low tension, 150 kv-a. maximum

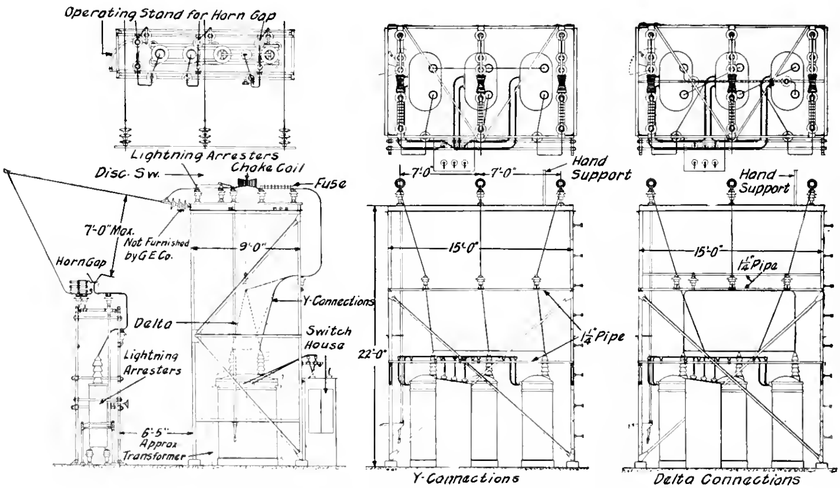


Fig. 5. Standard Outdoor Substation, steel structure mounted, three-phase, 45,000 volts maximum high tension, 15,000 volts maximum low tension, 1500 kv-a. maximum

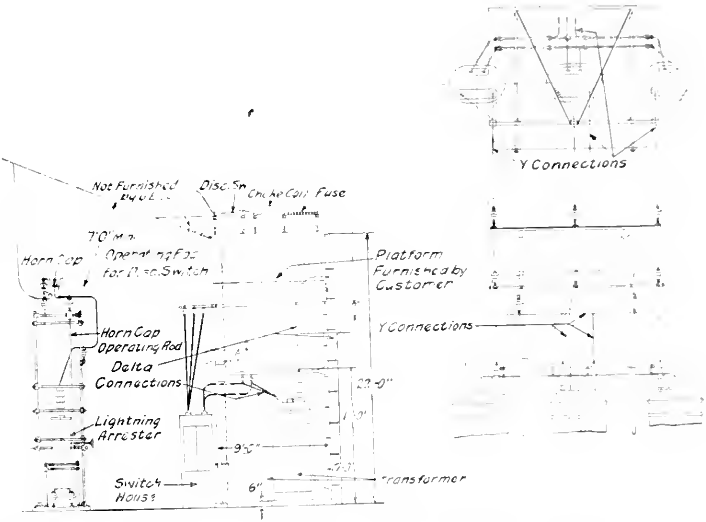


Fig. 6. Standard Outdoor Substation, steel structure mounted, 45,000 volts maximum high tension, 15,000 volts maximum low tension, 1500 kv-a. maximum

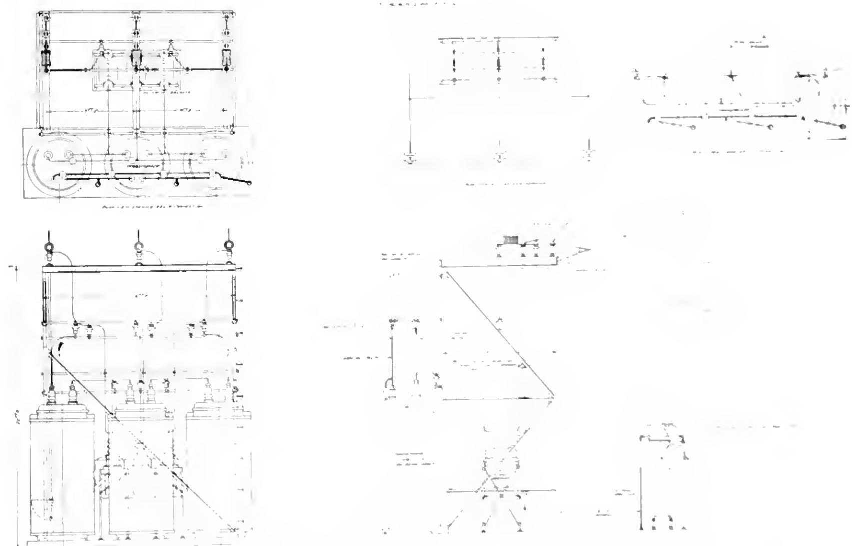


Fig. 7. Standard Outdoor Substation, steel structure mounted, three phase with oil circuit breaker, 45,000 volts maximum high tension, 15,000 maximum low tension, 3000 kv-a. maximum

One steel switching tower (hot galvanized).

Three single-phase, step-down transformers.

One low-tension switch and meter house.

One triple-pole, single-throw combined disconnecting switch, fuse and choke coil, with indirect (Fig. 5) or direct (Fig. 6) remote control hand-operating mechanism.

One aluminum lightning arrester.

Fig. 7 shows a substation having the transformers mounted on the ground level at side of tower. An outdoor oil circuit-breaker is used instead of a fuse. The substation supplies 3000 kv-a. (max.) three-phase

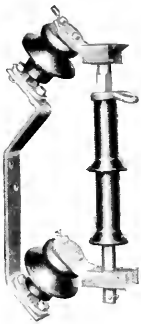


Fig. 8. Single-pole Combined Fuse and Disconnecting Switch, 45,000 volts maximum, 50 amperes maximum

at 45000 volts maximum high tension and 15000 volts maximum low tension. It is comprised of:

One steel switching tower (hot galvanized).

Three single-phase, step-down transformers.

One low-tension switch and meter house.

One triple-pole single-throw combined disconnecting switch and choke coil, with direct remote-control, hand-operating mechanism.

One triple-pole, single-throw outdoor oil circuit-breaker hand-operated with handle at switch.

One aluminum lightning arrester.

EQUIPMENT

The general features of standard outdoor substations having been enumerated, the detailed parts of the equipment will be grouped and discussed as follows.

(1) Primary

  (a) Steel towers.

  (b) Lightning arresters.

  (c) Single-pole combined disconnecting switch and fuse.

  (d) Triple-pole combined disconnecting switch, choke coil, and fuse.

  (e) Oil circuit-breakers.

  (f) Transformers.

(2) Secondary.

  (a) Types and equipment of switch and meter houses.

Steel Towers

The steel towers shown in Figs. 3 to 7 inclusive have been used largely for standard outdoor substation structures. The tower shown in Fig. 3 is of heavy steel construction

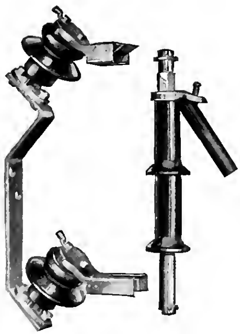


Fig. 9. Single-pole Combined Fuse and Disconnecting Switch, 45,000 volts maximum, 50 amperes maximum

and is painted. The other towers are hot galvanized.

The erection of the tower is a simple matter, as all members are marked to correspond with similar legends on the erection drawing. The members are bolted together with galvanized bolts and nuts. The main upright members terminate in supporting feet which are anchored by four anchor bolts to a suitable concrete base.

The structures are portable and the whole station may be dismantled in a few hours by unskilled labor, picked up, transported, and erected in just as permanent a manner at another location.

Lightning Arresters

The question of lightning protection for outdoor substations is largely a matter of initial cost. Effective protection is expensive, but on the other hand the cost of inefficient protection is also expensive and unwarranted. For protection of circuits up to and including 14000 volts, the graded-shunt resistance multigap or the compression-chamber multigap arresters are suitable. Neither of these arresters, however, is as sensitive to high-frequency disturbances as is the aluminum arrester, but its cost is less and it is better than no arrester on circuits of this voltage.

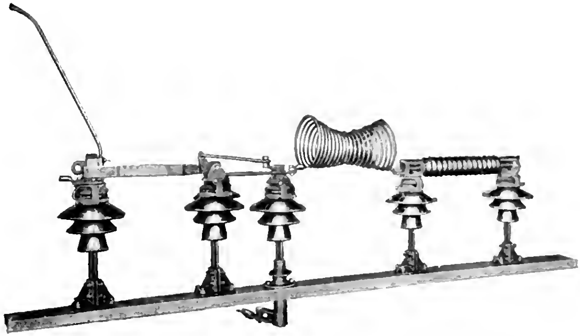


Fig. 10. Single-pole Combined Disconnecting Switch, hourglass choke coil and fuse, 45,000 volts maximum, 50 amperes maximum

For protection of circuits above 14000 volts, the most efficient arrester is the aluminum type. This arrester has a higher initial cost and requires almost daily attendance. The matter of attendance may in some installations prohibit its use, and in such cases it is often advisable to omit the arrester and to depend upon the choke coils for holding the disturbance back on the main line where it can be taken care of by the arresters at the main or substation nearest to the outdoor substation.

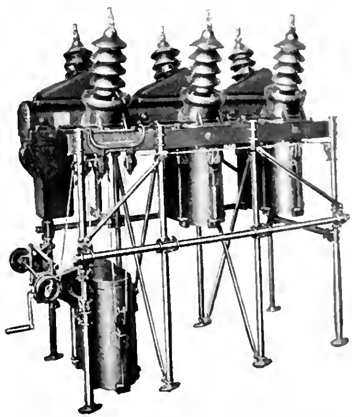


Fig. 11. Standard Outdoor Oil Circuit Breaker, hand operated, mounted on self-supporting framework

In connection with the protection of large stations, the initial cost of the arrester and the cost of daily attendance should be carefully balanced against the first cost of the apparatus to be protected. It is on this basis that the aluminum arrester is included in the equipment of the standard outdoor substation of 150 kv-a. and above.

Single-pole Combined Fuse and Disconnecting Switch for Use up to 45,000 Volts

The combined fuse and disconnecting switch, Figs. 8 and 9, is intended for short-circuit protection or for opening the exciting current of small transformer banks, and should never be used to open the primary side of the substation under load.

It should be mounted in a vertical position as shown in Fig. 1 and should be operated from the ground or a suitable platform by a hook. This unit is suitable for use up to 50 amperes. The fuse passes through the center of a treated fiber tube which, in turn, is enclosed in a fuse holder of built-up porcelain petticoat insulators. The upper end of this holder is closed and the lower end is open. The cross-section of the fuse is slightly less near the closed end of the holder, and it is here that melting takes place when a short circuit of sufficient magnitude occurs. The expulsion, consequent upon the expansion of gases formed, expels the arc through the lower open end of the holder and clears the circuit. Because of this explosive action of the fuse downward, it should be so located as not to endanger other apparatus.

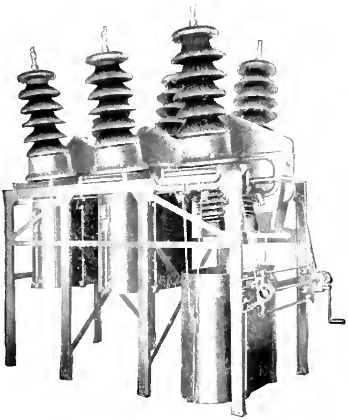


Fig. 12. Standard Outdoor Oil Circuit Breaker, hand operated; mounted on self-supporting framework

Triple-pole Disconnecting Switch, Hourglass Choke Coil, and Fuse for Use up to 45,000 Volts

This combination, the single-pole element of which is shown in Fig. 10, is mounted in single-pole units on a channel-iron base. Each phase therefore has a separate channel iron which is fastened to the steel tower. The unit will thus not jar loose or out of alignment, for the alignment is dependent entirely upon the channel-iron base.

The disconnecting switch is operated by movable insulators (one for each pole of the switch, connected together by auxiliary operating rods and bell cranks) being revolved by an operating handle located on and supported by an angle iron riveted across the lower part of the tower. This handle is connected to one of the movable insulators by a galvanized iron pipe. The handle can be locked in the open or the closed positions.

As the movable insulator revolves, a crank shaft transmits the motion to the switch blade which in opening describes an arc of 90 degrees in a plane perpendicular to the switch base. Any sleet or ice which has formed on the wedge-shaped contacts is removed by the action of the double end of the switch blade which straddles the contacts when in the closed position.

The switch is suitable for breaking the exciting current of transformer banks up to 15000-kv-a. capacity. This rupturing is assisted by horn-type arc deflectors mounted on the cap which supports the stationary contacts. The double-end switch blade previously mentioned straddles this deflector. When the switch is opened, the blade moving

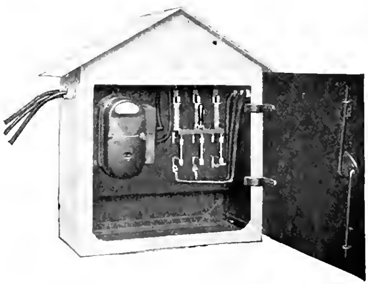


Fig. 13. Standard Outdoor Switch House, structure mounted, 60 cycles, three-phase, 220 volts, 200 amperes

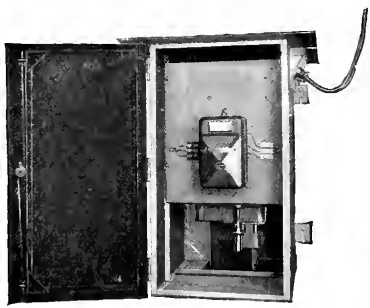
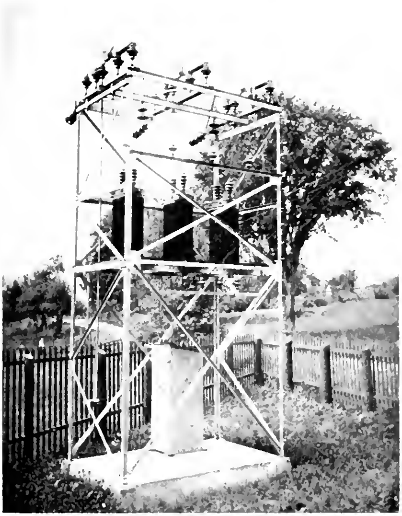
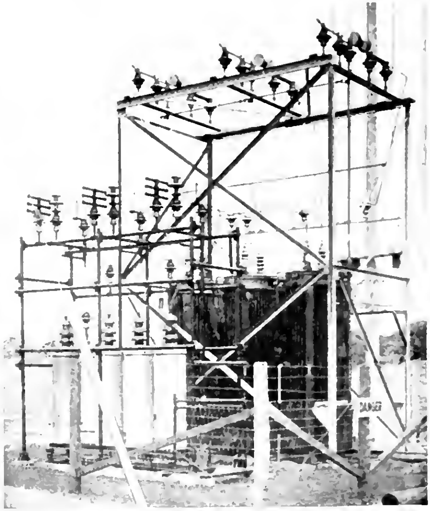


Fig. 14. Standard Outdoor Switch House, structure mounted, 60 cycles, three-phase, 2300 volts, 200 amperes

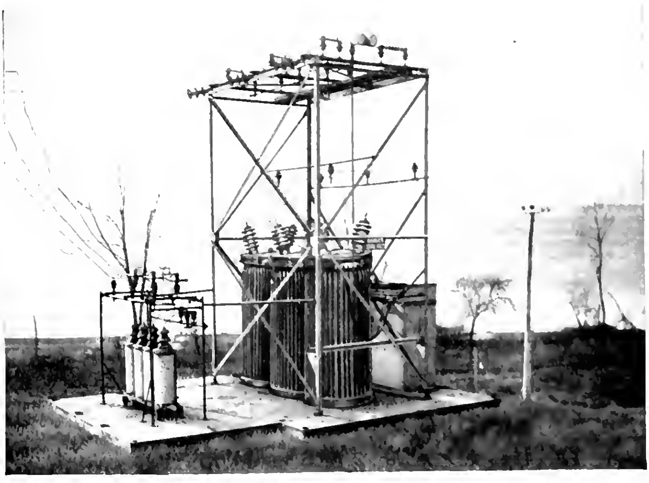
To open the fuse, the holder is lifted completely out of the contacts, and if desired the upper end of the holder can be inserted in and hung from the lower contact clips. These clips are protected against the effects of ice, sleet, and snow by a hood attached to the top of the supporting insulator.



Standard Outdoor Substation, steel structure mounted, three-phase, 60 cycles, 33,000 volts high tension, 2300 volts low tension, 150 kv-a.



Standard Outdoor Substation, steel structure mounted, three-phase, 60 cycles, 33,000 volts high tension, 2300 volts low tension, 1500 kv-a.



Standard Outdoor Substation, steel structure mounted, three phase, 60 cycles, 22,000 volts high tension, 440 volts low tension, 750 kv-a.

upward confines the arc to the horn and quickly ruptures the arc.

The fuse is mounted horizontally and must be removed by hand. Before it is removed however, the line must be opened by the disconnecting switch. The fuse is satisfactory for use up to 50 amperes and it is for short-circuit protection only. When it melts, it forms a gas which expels the arc at the rear end of the holder thus clearing the circuit.

The fuse holder consists of a fiber tube enclosed in a porcelain housing. Each end of the tube is provided with a cylindrical contact which fits securely into a spring contact clip mounted on the supporting insulator cap. These clips are enclosed in a shield to prevent ice and snow from interfering with the removal of the holder.

Both the switch and fuse can be kept in a satisfactory operating condition by the liberal application of a heavy lubricant applied to the moving parts as often as climatic conditions require.

The hourglass choke coil consists of a coil of bare copper wire, wound in an hourglass shape, supported at one end by the last disconnecting switch insulator, and at the other end by the first fuse insulator. The turns are air insulated. Should an extremely heavy disturbance cause arcing between the turns, they will reinsulate themselves upon the removal of the disturbance.

Eye holes are provided at each end of each unit, not for dead ending the line, but to prevent any strain on the terminal from breaking the main connections.

When it is necessary to dead end the transmission line on the tower structure, strain insulators should always be employed, and for this purpose use should be made of the same type of insulators as are used on the main transmission line itself.

As will be noted in connection with the standard outdoor substation shown in Fig. 7, the foregoing combination is also used with the exception that the fuse is omitted. That is, the disconnecting switch and the hourglass choke coil are mounted together as a unit. The capacity of the substation in question prohibits the use of the fuse (max. capacity 50 amperes), and where short-circuit protection is required an outdoor oil circuit breaker is substituted. The use of the oil circuit breaker also permits opening the line under power load.

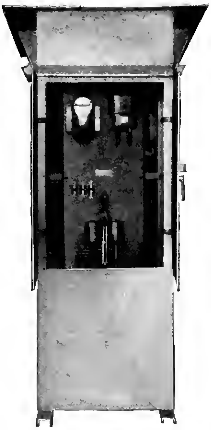


Fig. 15. Standard Outdoor Switch House, ground mounted, 60 cycles, three-phase, 600 volts, 800 amperes

Fig. 16. Standard Outdoor Switch House, ground mounted, 60 cycles, three-phase, 600 volts, 2000 amperes

Fig. 17. Standard Outdoor Switch House, ground mounted, 60 cycles, three-phase, 2300 volts, 500 amperes

Outdoor Oil Circuit Breakers

Automatic or non-automatic outdoor oil circuit breakers are also used in connection with the standard outdoor substation as shown in Figs. 11 and 12. The construction may be described in general as follows:

Each pole of the oil circuit breaker consists of a separate top-connected unit mounted in a steel tank. These tanks are arranged for either floor or framework mounting. For outdoor substations, the framework type of mounting is best.

Each unit consists of two bushings, with fixed contacts extending into the oil, and an operating mechanism with movable contact blades, both secured to the cast-iron cover of the heavy sheet-steel tank.

Oil circuit breakers for the standard outdoor substation are usually operated by a removable lever at the breaker. Solenoid or remote hand-operated mechanisms are sometimes used however.

Automatic breakers are provided with an instantaneous or time-limit tripping mechanism located at the breaker. Trip coils may be energized from standard current transformers or from bushing-type current transformers mounted on the breaker bushings.

High-grade mineral oil, having high flash and ignition points and low carbonizing properties, is used in each breaker. Low-temperature oil of the same properties is used where low climatic temperatures occur.

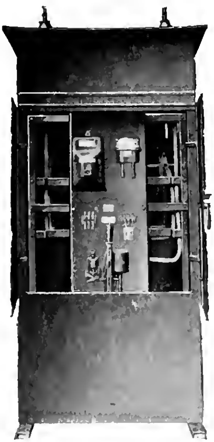


Fig. 18. Standard Outdoor Switch House, ground mounted, 60 cycles, three-phase, 6600 volts, 500 amperes

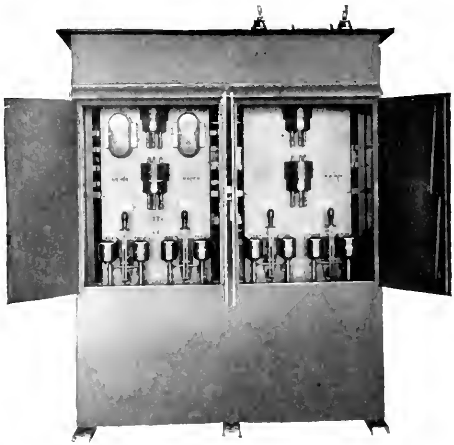


Fig. 20. Special Outdoor Switch House, ground mounted, four circuit, 60 cycles, three-phase, four-wire, 4000 volts, 300 amperes per circuit

Transformers

Transformers form an essential and highly important part of a standard outdoor substation. Owing to their many types—voltage ratings and connections—it is not possible in this article to designate what type of transformer should be used with the different types of substations. Transformers for this service include all the desirable features incorporated in indoor types. Additional features are included for successful outdoor operation under varied climatic conditions where reliable weather-proof construction is essential.

Standard sizes and voltage ratings have been established which cover all outdoor substation requirements.

Secondary Switch and Meter Houses

The applications of the outdoor switch house are many and varied. A large number of different types have been developed. These can control single-phase, two-phase, or three-phase, three-wire circuits, or three-phase, four-wire circuits ranging from 110 to 15000 volts, and are of capacities from 5 to 1500 amperes. Switch houses controlling single, double, and even four circuits have been built and are now in service. It is not the intention of this article to describe all of these many different types, but merely to review the types which are usually furnished in connection with the standard outdoor substation.

The equipment shown in Fig. 13 is adapted for structure mounting, with side-entrance bushings, for the control of 60-cycle single-phase two-wire, single-phase three-wire, or three-phase three-wire circuits. It ranges in capacity from 110 to 220 volts, and 5 to 150 amperes.

The equipment shown in Fig. 14 is adapted for structure mounting, with side entrance bushings, and removable steel meter panel, for the control of 60-cycle single-phase two-wire, or three-phase three-wire circuits. It is designed for 2300 volts and ranges in capacity from 5 to 200 amperes.

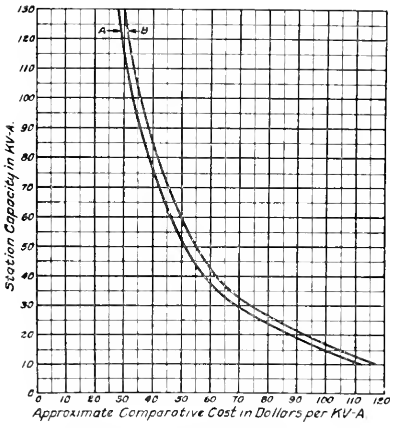


Fig. 21

A—Pole mounted as in Fig. 1, 15,000-volt primary, 2300-volt secondary
B—Pole mounted as in Fig. 2, 35,000-volt primary, 2300-volt secondary

The equipments shown in Figs. 15 and 16 are adapted for ground mounting with side-entrance bushings, for the control of 60-cycle single-phase two-wire, three-phase three- or four-wire, or two-phase four-wire circuits. They range from 220 to 600 volts, that in Fig. 15, 5 to 800 amperes, and that in Fig. 16, 1000 to 2000 amperes.

The equipments shown in Figs. 17 and 18 are adapted for ground mounting, with roof entrance petticoat type leads for the control of 60-cycle single-phase two-wire, three-phase three- or four-wire, and two-phase four-wire circuits. Their capacities are as follows: Fig. 17, 2300 volts; Fig. 18, 3500 volts to 6600 volts, 5 to 500 amperes.

Several switch houses have been developed to meet special requirements. Two of these types are shown in Figs. 19 and 20.

The general specifications for switch houses are given in Table I and in the following:

TABLE I

CONSTRUCTION

Framework......	Angle iron.
Covering of sides.	Galvanized sheet iron, fastened to framework by bending around angle iron.
Roof...........	Galvanized sheet iron plate, riveted to framework.

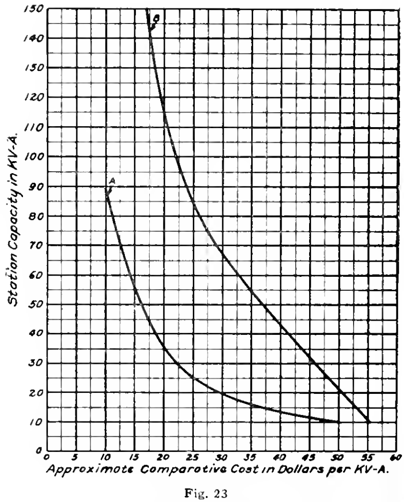


Fig. 23

A—Steel tower mounted as in Fig. 6
B—Steel tower mounted as in Fig. 7, 35,000-volt primary, 2300-volt secondary

Doors...........	Galvanized sheet iron in two sections.
Hinges..........	Cast iron, concealed, mounted inside, two per door.
Latch and Hook..	Cast iron, locking door in three places on inside. Provision for padlock.
Paint...........	One coat of red lead inside and outside, plus one coat of grey weatherproof paint outside.

EQUIPMENT

Panel...........	Marine finished slate or steel plate, width to suit equipment.
Entrance leads...	Porcelain bushings for through cable up to 600 volts. Petti-

coat insulators with through stud and terminal up to 15000 volts.

Main connections. Circuits up to 600 volts, above 200 amperes; cable.
Circuits above 600 volts, up to 500 amperes; insulated copper wire or insulated bars, depending upon capacity.

Apparatus

It will not be possible in this article to discuss in any detail the apparatus used in the various switch houses. Standard indoor apparatus, such as instruments, instrument transformers, oil circuit breakers, etc. is used throughout.

Where necessary, the apparatus is adapted for outdoor service by making all moving parts, such as pins, links, springs, etc., non-corrodible. This practice together with the protection given to the equipment by a weatherproof housing eliminates any trouble due to corrosion. It is expected of course that the apparatus will receive reasonable attention.

All switch houses have provision for padlocking. As will be noted from Fig. 14, the house is equipped with an easily removable steel panel, mounting the watthour meter. This panel protects the operator, but can be removed when necessary to inspect the apparatus mounted on the sides of the house back of the panel.

The house shown in Fig. 17 is equipped with both a front and a rear door. A removable lower section in the rear allows the back of the house to be entirely opened for the inspection of apparatus, the removal of the oil circuit breaker tank, etc. It is intended that the front and rear doors be locked with different padlocks.

The operator (the person who has authority simply to close the breaker in case it goes out on overload) is provided with a key to the front door padlock. This allows the operation of the oil circuit breaker, but the slate panel protects the operator from coming in contact with high-voltage apparatus.

The inspector (the person who has authority to make repairs, inspection, etc.) is provided with keys to both doors. This allows of ready inspection of all apparatus.

COSTS

The choice of the most economical type of standard outdoor substation depends mainly upon the initial cost of the station. It is impossible in this article to give exact information on this cost, but some approximate figures may be obtained from the following curves showing cost per kilovolt-amperes. These curves do not include the cost of erection (material and labor) nor the necessary enclosure for the station such as fence, etc. These costs will vary according to the location and the costs of raw materials.

A few of the actual installations of the standard outdoor substations are shown on pages 588 and 647.

In conclusion, it may be noted that the standard outdoor substation is not only a practical means of furnishing electrical energy to isolated communities and rural consumers, but it is also a paying investment. Both

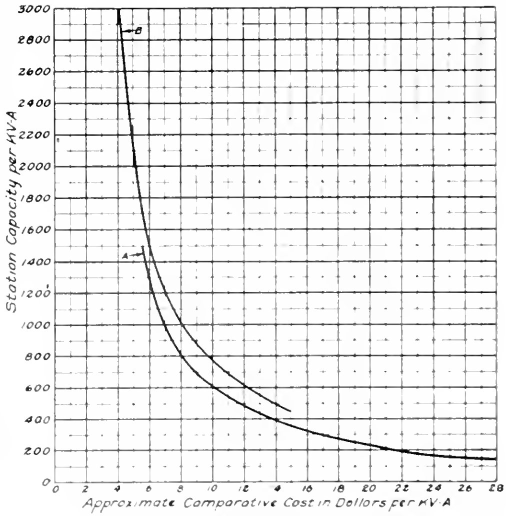


Fig. 22. A. St[illegible] B. St[illegible] in F[illegible]

initial and operating costs are comparatively low and good elec tric service can be offered at attractive prices. Furthermore, the present day demand for economy and efficiency warrants the use of this type of sub-station where it is at all possible; especially for inter-connection between central station companies.

The results which are being obtained by this type of station and the large number which are being installed in all parts of the country prove conclusively that the standard outdoor substation satisfactorily meets operating conditions and at a minimum of expense.

Bibliography of Electric Welding

1918–1914

By William F. Jacob
Librarian, General Electric Company

With whole-hearted zeal to win the war quickly, the entire country is responding to the slogan: "Ships, more ships, and still more ships." Every ounce of energy is being expended and shipyards are working feverishly to "build a bridge of ships to Pershing" Every method is employed to encourage the individual workman to speed up Prizes are offered for the greatest number of rivets headed daily.

Now, a simpler way appears—weld the parts together By this method it is not necessary to drill or punch holes for rivets, nor is it necessary to match up the holes nor are the plates weakened as might be the case when they are punched. Welding thus reduces delays in the drafting room and machine shop. By the electric process, the parts of the hull are fastened together and the seams are caulked. Moreover, the average welding operator can turn out somewhat more work than the average riveter. In fact, the latest information indicates a saving of about 25 per cent in labor, time, and cost by the introduction of electric welding in shipbuilding. Thus electric welding will in time probably supplant riveting to a considerable extent because speed is the first and foremost requisite; and, if in selecting the speedier method we do not sacrifice strength, the choice is a wise one.

Nor is construction the only modern application of electric welding to marine work. This type of welding is used extensively in repairing of all kinds. Probably the best tests of its adaptability to this field were made on the interned German liners. At the outbreak of war with the German Government, our naval authorities found the boilers and engines of these vessels so badly damaged as to appear at first as if hopelessly beyond repair. This was, in fact, the aspiration of German crews. Little was published about the ships for several months, but soon the joyful news was given out that every one of the ships had been successfully repaired and commissioned by the U. S. Navy. It will make anyone's heart quicken to read Commander Jessop's and Naval Constructor Knox's illustrated articles in the *Journal of the American Society of Naval Engineers*, November, 1917, describing in a professional way how Yankee ingenuity saved the day. Electric welding did its share in this work, and it is also widely employed in repairing ships after accidents or naval engagements.

Electric welding is used to supplant riveting in some structural work; to join rails on street-railways; to assemble transformer tanks; to repair locomotives; to repair castings, and to make cheaper machine tools. Electric arc cutting is used to cut metals and to salvage structural members. All in all these are arts which are advancing rapidly year by year.

To show the progress of the art of welding in the past few years, a bibliography is appended. This is part of the "Report on the Application of Electric Welding to Ships" by Capt. James Caldwell, R. E.,* issued by the Emergency Fleet Corporation. Captain Caldwell worked in conjunction with the Electric Welding Committee of the U. S. Shipping Board Emergency Fleet Corporation, and gave valuable information to this committee which helped to strengthen the belief that welding will prove superior to riveting. A yard has been designed with fabricating shops adjacent to the ways, and the transportation and handling is planned so as to be standardized in all the shipyards manufacturing fabricated ships. A general article giving a good résumé of this work, as well as the activities of the above committee, is given in a special supplement to the *Nauticus* dated June 1, 1918.

The following list of references was compiled by the General Electric Company's Library a few months ago and was brought up to date by the Engineering Societies Library at the request of Prof. Bradley Stoughton of the National Research Council. For those who are interested in the earlier history of the art, a valuable bibliography for the period 1786–1913 was compiled by Mr. Wm. B. Gamble of the New York Public Library, and was published in 1913 by that Library.

If any reader has difficulty in obtaining any of the articles referred to, the author will endeavor to assist on request.

* Deputy Assistant Director of Materials and Priority, Admiralty, London.

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Gives current consumption and costs.

Backing American Ships with American Dollars

By Edward N. Hurley

Chairman United States Shipping Board

This article is part of a series by Mr. Hurley dealing with after-war phases of our rapidly growing merchant marine. The information is offered with the purpose of stimulating business thought about our new merchant marine, and aiding in the business changes that will be needed to make American ships most useful to this and other nations, during the war and afterwards.—Editor.

The United States is the greatest coffee consuming nation in the world.

We buy every year from Brazil about $100,000,000 worth of coffee. Potentially, that should be the greatest influence for sales of our own products to Brazil. Actually, this coffee consumption has yielded to the United States only a fraction of its potential benefits.

European shipping concerns have controlled practically all shipments from Rio de Janeiro and Santos to New York and New Orleans. About two thirds of the coffee comes to New York and one third to New Orleans. An average of three ships a month were required in normal times to carry to New Orleans the 2,000,000 bags for the South and Middle West. In a well-balanced trade, these ships would have been available for return cargoes of American products.

The Middle West, especially, might have been in an advantageous position, because it could command lower railroad rates to New Orleans than New York. But the ships of this coffee fleet, all under foreign flags, made no effort to secure return cargoes. After discharging coffee, they loaded with cotton and other raw materials for European manufacturers. They steamed away to Europe, took on cargoes of manufactured goods made largely from American raw materials, and carried these back to Brazil.

Lacking ships to South America and banks on that continent our coffee importers had to pay exchange and commission to European banks. The foreign ships upon which we depended provided a smooth highway for Brazilian coffee into New Orleans, greased the way for American raw materials to reach European mills, and carried European goods to Brazil, where they were paid for with the Brazilians' profits on sales of coffee to the United States. These foreign ships were so routed that they rendered their first service to the European exporter, their second service to the Brazilian coffee grower—and we came in for service after that.

Our foreign trade has been full of opportunities like this. But, lacking American merchant ships and American banking facilities in other countries, we have let the foreigner improve the opportunities.

Now we are building a real merchant marine. American banks are establishing foreign branches. The American ship and the American dollar are going to work together, and the more attention we pay to this great field of business the harder they will work for us.

Shipbuilding for war purposes has made a tremendous appeal to the American imagination. We must now put our merchant marine into the nation's thought in just the same way. These are the nation's ships. They will increase prosperity for people in the corn belt even more than those on the seaboard. They will serve the farmer and consumer even more than the manufacturer and exporter. When we get the American merchant marine into the daily thought of every producer, and our boys and girls play with shipping toys, and American youth consider the sea in choosing a career, then we shall have something upon which to build foreign trade, foreign exchange, foreign investment.

War has made us a real creditor nation. We have bought back from European investors billions of dollars worth of American securities. We now own our own railroads and factories, and hold the bonds issued by our state, county, and municipal governments. We have lent billions of dollars to the allies, and will lend them billions more before the war ends. We have opened book accounts with nations not actively engaged in the war who want to buy goods on credit from us. Best of all, we have begun to learn new habits of thrift and investment through buying liberty bonds, so that peace ought to find us with the mortgage of foreign investments on this country paid off and money in pocket to lend other nations.

The world owes us a great deal of money. But our principal debtors are the great manufacturing and exporting nations, like England, France, and Italy. Naturally, they will pay their debts in goods as far as possible, and much of the trade which grows out of these obligations will take the form of shipments of American raw materials to make the goods with which they will pay us. Necessity will also lead them to be active sellers of manufactured goods in South America, the British colonies, and the Orient, and in that trade there will never be either American competition or jealousy over business that properly belongs to them, because we realize the enormous sacrifices they have made for humanity, and wish to see them return to peaceful prosperity as fast as possible.

But there is trade to be built on new shipping routes between this and other countries. More than that, there is service to be rendered other countries by our ships and money.

Let us take Brazil as an illustration. When American ships go to Rio and Santos for coffee, they will carry American officers and seamen. There are no better salesmen or creators of good will in the world than the men who man merchant ships running on regular lines from one country to the other. For their employment depends largely upon freight traffic. With our coffee, brought to us in American ships, and paid for in American manufactures sent back to Brazil, our officers and sailors will work like those of other nations to get freight.

With our manufacturers making payments in goods to Brazil, there will be a direct money exchange between Rio and New York, Santos and New Orleans, instead of the old triangular payment of money by American coffee importers to Brazil through European banks. So American dollars will be working with American seamen to safeguard the trade that belongs to us.

What sort of manufactured goods will our ships carry back to Brazil?

Some of the stuff will be for consumption, such as textiles, shoes, hats, millinery, agricultural implements, office equipment, household furniture. But Brazil needs production and public service equipment as well. The Balkan war diverted European capital from her industries and communities. The world war has put her on still shorter allowances. Her prosperity thus far has rested on two products coffee and rubber. The development of rubber plantations in the East Indies has decreased her sales of crude rubber and awakened her to the necessity of wider agricultural development cattle raising, grain growing, and the like. This calls for investments in agricultural enterprises, the settlement of new lands, the building of new railroads, the financing of new communities. Brazil also possesses vast undeveloped water power, and is endeavoring to establish manufacturing industries. She will need a market for her bonds and stocks, and if the American dollar helps her to create the basis of prosperity, it will be followed by American electrical machinery, railroad equipment, and other apparatus, thus creating freight for the return voyages of American merchant ships operating regularly in the Brazilian coffee and passenger trade.

Ships are the keystone of this whole elaborate structure.

Our trade abroad has grown haphazard, like Topsy, and become lopsided in many ways. It has been unbalanced financially, so that our profits have gone to pay foreign shipping companies, bankers, and insurance brokers. It has been unbalanced in tonnage, so that while we bought products of other nations and should have been building trade with them in finished goods, we have merely supplied raw materials for other manufacturing nations. We have been set aside on one leg of the triangular voyage when we should have been doing business direct, give and take, as we do it at home — you deal with me and I deal with you. Our foreign trade has grown against every handicap simply because of excellent American products which overcome competition on merit.

Ships are the rallying point round which we must pull all this business together, and now is the time for every American to begin studying our merchant ships and all that goes with them in the way of ocean delivery service, foreign exchange and investments, sales of American products for the out voyage, and purchases or raw materials for the return trip. We will shortly have the ships. It is time to acquire the knowledge of ships which will enable us to utilize our new merchant fleet for the service of this and other nations.

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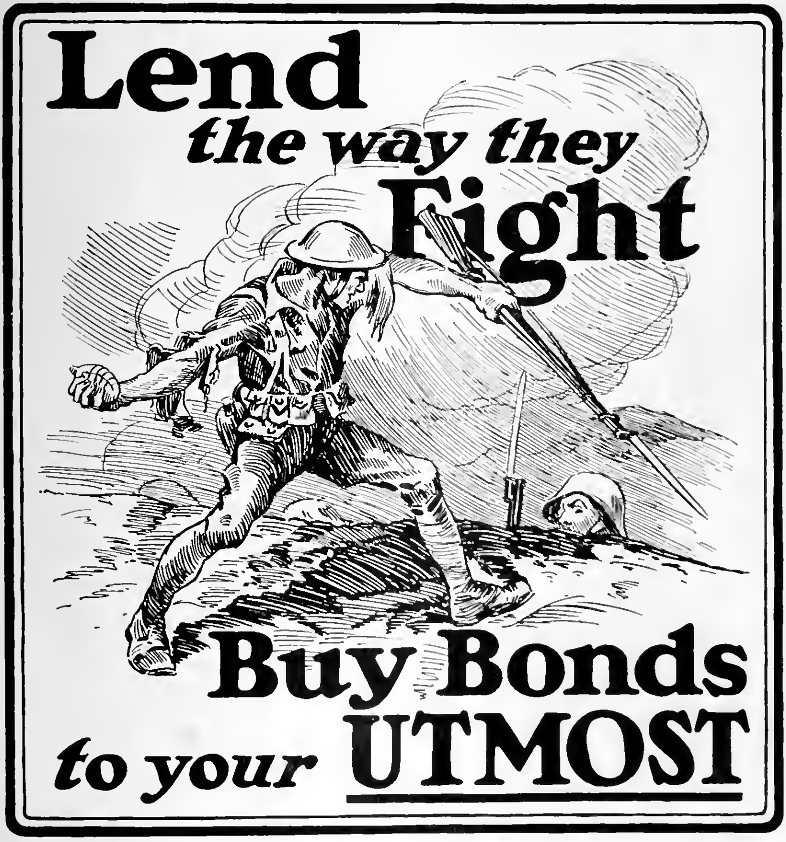

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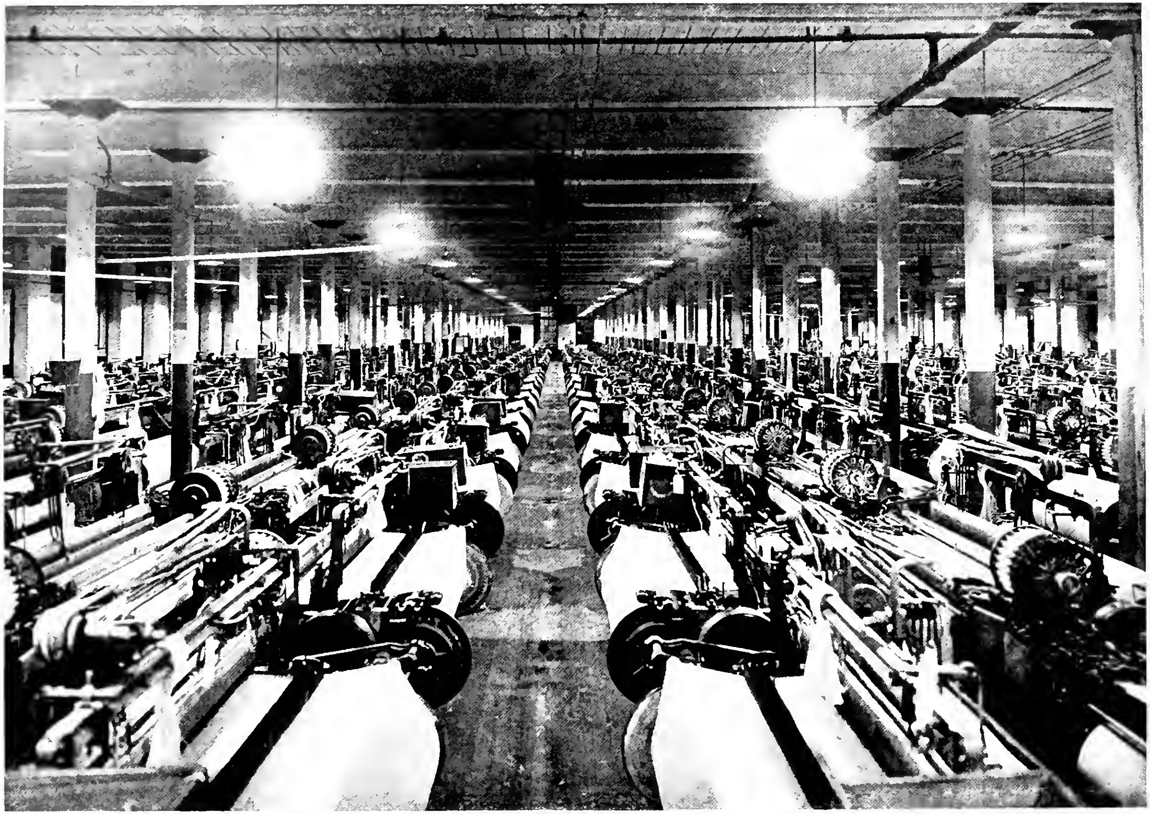

A Few Years ago Looms Were Usually Lighted by Small Incandescent Lamps in Deep Bowl Steel Reflectors, Hung Close to the Work. In some of the more recent installations medium sized Mazda C lamps in enamel dome-shaped steel reflectors are used. These are hung high, well out of the ordinary angle of view, and provide evenly distributed general illumination. This system makes the room feel more cheerful and all parts of the machines are rendered clearly visible. This weave shed is lighted by 100-watt Mazda C lamps in enamel dome reflectors, hung 12 feet high on centers 12 by 22 ft. (See articles pages 674 and 681.)

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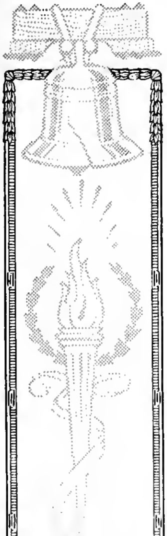

THE WHITE HOUSE
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Again the Government comes to the people of the country with the request that they lend their money, and lend it upon a more liberal scale than ever before, in order that the great war for the rights of America and the liberation of the world may be prosecuted with ever increasing vigor to a victorious conclusion. And it makes the appeal with the greatest confidence because it knows that every day it is becoming clearer and clearer to thinking men throughout the nation that the winning of the war is an essential investment. The money that is held back now will be of little use or value if the war is not won and the selfish masters of Germany are permitted to dictate what America may and may not do. Men in America, besides, have from the first until now dedicated both their lives and their fortunes to the vindication and maintenance of the great principles and objects for which our Government was set up. They will not fail now to show the world for what their wealth was intended.

Woodrow Wilson

Electrodes for Electric Furnaces: Their Manufacture, Properties, and Utilization

By Jean Escard

Civil Engineer, France

Part I

The number and importance of the products of electric furnaces are not generally realized. As we pointed out on the editorial pages of our February 1918 issue, we are indebted to the electric furnace for aluminum, silicon, calcium carbide, high-speed steels, graphite, carborundum, etc. Even the armor plate for our battleships is poured from electric furnaces using huge electrodes manufactured from coal by electric power. In many of these electrical processes the chemical composition and physical properties of the electrodes have considerable influence on the character of the product and the cost of manufacture, and we feel that this article, which is a translation from the French and was originally published in *Le Genie Civil*, Vol. 71, Nos. 5, 6 and 7, will be of special interest to our readers. The present installment describes the raw materials from which electrodes are manufactured, the process of manufacture, and some of the chemical and physical characteristics of carbon electrodes. The second installment, which will be published in our November number, will consider the shape, size, and arrangements of electrodes in the furnace; the life, wear, and protection of electrodes and electrode holders, cooling systems, and methods of attaching connection. A short discussion will also be included on metallic and composite electrodes.—Editor.

The conductors which, in any given form, serve to connect the external electric circuit with the material to be treated inside the furnace have come to be called electrodes in electro-thermal industries. Their physical and chemical nature, their position or arrangement inside the furnace, their electrical and mechanical properties, and their mode of fabrication exercise a decided influence upon the quality of the products finally obtained as well as upon the output and the efficiency of operation. Hence, it is not astonishing that their manufacture should be surrounded with so much care and that so many tests are necessary in order that they may measure up fully to the demands of the many productions of electro metallurgy. Hence, the study of electrodes is of very great practical interest.

Electrodes used in electric furnaces must answer the following requirements:

(a) They must be refractory in order that they may not be destroyed by the thermal or calorific action of the current and of the electric arc (3500 deg. C. approximately). Carbon is one of the most refractory materials known; it does not melt even in the presence of the highest temperatures and volatilizes only in the electric arc, and it fulfills quite well the demands of manufacture.

(b) They should conduct electrically at all temperatures.

(c) They should be medium poor heat conductors in order that they may not dissipate to the outside an unduly great amount of the heat from the furnace.

(d) They should not exercise harmful chemical effects upon the reaction to be produced in the furnace.

We will see later on that, with regard to the foregoing set of conditions, it is only carbon that more or less satisfies these various desiderata in the majority of electro-thermal manufacturing processes. However, there are certain special industries in which materials other than carbon, in particular certain metals and alloys or even mixed compounds, must be used in place of carbon, and actual experiments have shown that a number of these give better results than carbon electrodes for some particular products.

Consequently, electrodes for furnace service may roughly be divided into two chief classes, viz.: (1) electrodes made of carbon (either amorphous or graphitic), and (2) metallic electrodes and (composite) electrodes manufactured from compound substances.

I. CARBON ELECTRODES

Manufacture

The first carbon electrodes intended for metallurgical work were made from a mixture of anthracite, bituminous coal, and tar. The whole was shaped under pressure in moulds, the baking subsequently taking place at around 1000 degrees. These carbons were very impure, not compact, and were only fairly good electric conductors. The processes have been improved, and now electrodes are made of great hardness and durability, and possessing sufficiently good conductivity, these qualities being achieved by increasing the pressure applied after moulding, and by graphitizing either partially or wholly the carbon used.

Electrodes of Amorphous Carbon

The manufacturing process comprises essentially the following stages: selection of the raw materials; the calcination and chemical purification (if this is deemed necessary) of the materials; mixing and kneading, followed by the moulding of the paste with the binder: and finally the baking at high temperature.

Raw Materials

Gas retort coal, anthracite, tar-coke, or petroleum-coke are employed as raw materials. The starting material used in the manufacture consists of a substance rich in carbon and as free from ashes and volatile ingredients as possible. The agglomerant or binder consists of dehydrated tar or dry coal tar residues, that is pitch. For a number of years a substance intermediate between these two has been used, which is specially adapted to the manufacture of electrodes. It is semifluid at ordinary temperature and is known in some localities as "electrolytic pitch."

Retort coal is but little used in aluminum works because it is ordinarily too rich in silica as a result of the fragments of refractory paste which remain adherent. But retort coal electrodes are quite frequently employed in electro-siderurgical plants, because the presence of silica does not offer any inconvenience there. The chemical treatment, which consists of digesting in heat with a concentrated caustic solution followed by washing with a solution of low concentration, diminishes greatly the ash figure. This can be seen from the following example:

Elements in Ashes	Specimen No. I		Specimen No. II	
	Previous to Treatment	After Treatment	Previous to Treatment	After Treatment
Silica......	0.91	0.20	1.13	0.16
Iron oxides	0.62	0.26	0.86	0.19
Alumina..	0.41	0.08	0.60	0.36
Lime....	0.17	0.08	0.60	0.36
Total per cent.	2.11	0.54	2.59	0.71

It will be seen that the amount of ashes is thus changed from 2.11 and 2.59 per cent to 0.54 and 0.71 per cent respectively figures which represent a practically acceptable ash admixture.

Anthracite of exceptional purity, such as is mined in certain places, may be used without any prior treatment. However, in general anthracite contains more than 2 per cent ash, of which at least 0.35 per cent is silica. This latter figure is inadmissibly high for the production of aluminum; but when purified, such anthracite shows the following ash figures before and after treatment

Specimen No. I was Scotch anthracite, while Specimen No. II was Welsh anthracite. The limits of impurities that could be called permissible are 0.5 per cent for silica and 0.2 per cent iron oxide. It will be noted of what great advantage the chemical treatment is in the reduction of the ash percentage. In general, the anthracite is first degassed in one of the standard illuminating gas ovens, the gas produced being burned under the grate.

Elements in Ashes	Specimen No. I		Specimen No. II	
	Previous to Treatment	After Treatment	Previous to Treatment	After Treatment
Silica	5.00	0.84	0.78	0.20
Iron oxides	1.06	0.25	0.32	0.12
Alumina..	2.02	0.25	0.43	0.12
Lime and magnesium	1.16	0.20	0.53	0.13
Total per cent	9.24	1.30	2.06	0.57

Petroleum coke is one of the raw materials that is most extensively utilized, the ash content of which varies between 0.5 and 2.0 per cent according to origin. The petroleum coke supplied from the United States of America contains ordinarily less ash, while that from Rumania contains more. It is probable that the ash content, looked at from this standpoint, is mainly due to the quantity of fine sand that is carried along by the crude petroleum. The ashes contain, moreover, a noticeable amount of sulphur, ranging between 1.25 and 1.5 per cent. The coke is charged at the top of the purifying furnace, consisting of rectangular brick flues, and is taken out at the bottom. The charges are 100 kilos (about 200 pounds) and they are made every two hours, 50 kilos being taken out every hour. The coke remains in the apparatus for several hours; hence the yield is small, in fact about 70 per cent, while the difference is burned up. When carrying out the calcining process in horizontal retorts, only about 20 per cent of the raw material is lost, but the heating is costlier. After this operation has been finished, the coke still contains from 0.5 to 0.7 per cent ash, consisting principally of 0.5 per cent silica, 0.15 per cent iron oxide and alumina, and 0.05 soluble sulphur ashes.

Tar coke has more or less the identical characteristics of petroleum coke. It is treated in a like manner; but tar coke is not found on the market in such abundant quantities as the other kind.

Graphite is simply dried in an oven; but it will be seen below that natural or native graphites are but rarely employed as raw materials, because the artificial product obtained directly by means of graphitizing the electrodes is generally given preference in practice.

Crushing and Mixing or Kneading

No matter what particular kind of carbon is being used, the pieces obtained are reduced to the size of an egg in a crusher consisting of two steel jaws of the oscillating kind. The pieces are then brought into a hopper which distributes them to a ball mill. The proportion of fine and large grains must be such that an electrode of great density is obtained with a definite porosity, which is the index of a certain electric and thermal conductivity. The proportion should be approximately as follows:

Passing through sieve

No. 100	40 per cent
60	15 per cent
30	20 per cent
16	15 per cent
8	10 per cent

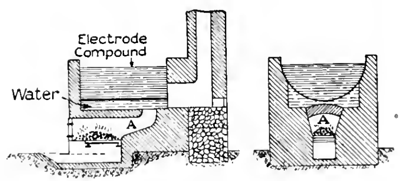
After leaving the crushing apparatus the coal powder is collected in bags, which are exactly weighed, and then tar is added. The latter operation is either carried out mechanically or manually.

The proportion of binder added should be as low as possible. Formerly, it used to be generally 30 per cent of the weight of coke employed; and even today this ratio is maintained in some places. In others only from 10 to 12 per cent tar is added. It would seem as though this latter figure were entirely satisfactory when the electrodes are made or drawn out under very high pressure. Pastes containing much tar, which as a consequence are more plastic, may be conveniently utilized for electrodes moulded by hand under low pressure.

In mechanical kneading processes the mixing is carried out in the vane or wing type of apparatus, the tar being previously dehydrated and heated in a vat or tank with a steam coil contained in it. The mixture, which is simply cooled on the ground and has the nature of a paste, is then triturated in wheel breakers by simultaneous crushing and reversing, whereby a perfectly homogeneous mass is obtained. In certain factories the mixing chamber is heated by steam and the temperature is raised to 90 degrees at the moment when the paste is taken out, the operation being effected with the aid of a worm or endless screw. These machines are charged with about 250 kilos (500 pounds) material.

The tar ordinarily used is of the medium heavy sort. For the manufacture of movable electrodes, it may contain from 40 to 45 per cent volatile substances. For fixed electrodes, such for instance as are used for the bottom or base of the furnace, a more fluid kind of tar is employed, that is, a material containing some 60 per cent volatile matter. The knowledge of the density gives no indication or clue whatever that would be useful from this viewpoint.

Where the kneading is effected by hand the machinery is of great simplicity (see Figs. 1 and 2). However, while in the case of mechanical mixers and kneaders external heating may be dispensed with because the heat set free by the friction of the vanes or wings suffices for heating the material, in hand-operated apparatus separate heating is indispensable and the kneader is heated either by a separate oven (A) such as is illustrated in Figs. 3 and 4, or by a steam jacket or an electric radiator. The latter method is the most desirable in plants where electric energy is procurable at low cost, such as in the majority of electro-metallurgic works.



Figs. 1 and 2. Hand-operated Kneading Machines to Work Electrode Paste. (Longitudinal and Transverse Section)

Moulding and Baking

The foregoing stages are followed by the moulding. For this operation draw presses bearing much resemblance to those employed for the manufacture of lead pipes are used, and are operated at a pressure of 300 kilos per square cm. of section (4250 pounds per square inch). The mass coming from the kneaders and mixers, while still hot, is brought into these presses, which are either worked electrically or hydraulically. The presses are capable of pressing between 30 and 40 blocks per hour. The mechanical drawing under pressure yields directly square or round prisms of sufficiently great length to make several electrodes at the same time by cutting. But the moulding can also be accomplished in cast metal moulds shaped like the electrodes, the paste being compressed by a hydraulic press. A still simpler method, followed in those places where the making of electrodes is only a side line, consists in stamping the paste into a cast metal mould by means of an electric or pneumatic rammer; sometimes this is done by hand. In these cases the proportion of binding material is a maximum.

In this state the electrodes are said to be "crude." While they have attained their ultimate form, it is necessary that they be baked at a high temperature to rid them of volatile ingredients, to render them harder and more compact, and to give them a higher electric conductivity. They are allowed to stand for a day or two after moulding, after which they are submitted to the baking process in a gas furnace of a kind resembling brick ovens, the electrodes being placed in crucibles of refractory earth. By this operation the tar binder is eliminated or converted into carbon. The furnace is of the continuous working kind, more specifically, the temperature is gradually raised to 1300 degrees and then reduced slowly to some hundred degrees. The circulation of the gases in these furnaces can be modified at will simply by replacing the connecting pipes.

In some cases furnaces with fixed combustion chambers and movable hearths are used, but this type of furnace is more expensive than the preceding pattern; but for high daily outputs they are otherwise more economical.

For the ordinary baking process muffle furnaces are often quite adequate (operated intermittently), or reverberatory furnaces analogous to the heating ovens in metallurgy work are used. In the latter case the electrodes are disposed parallel upon the bottom or hearth of the furnace, and are covered with a layer of coke dust upon which in turn is spread a layer of fine sand several centimeters thick to prevent superficial combustion.

The electrodes remain in the furnace for from 8 to 10 days for the baking and cooling. The cooling should be very gradual and slow in order that breakage in use may be avoided. When the electrodes have been thoroughly cooled, they are ready for use. Their density, which prior to baking was about 1.5, has reached a value ranging between 1.6 and 1.65. The porosity is from 18 to 20 per cent.

2. GRAPHITIC ELECTRODES

The manufacture of these electrodes is based upon the transformation, at very high temperatures, of amorphous carbon into graphite. It is performed by two different processes.

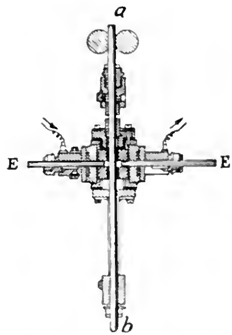


Fig. 3 Girard and Street Type of Furnace Used for the Manufacture of Graphitic Electrodes

(a) A French Method

In this process an electric furnace is used (see Fig. 3) consisting of a block of refractory material enclosing a parallelepiped of coal in which a cavity is formed for the heating chamber. Along the axis of the furnace there is a cylindrical or rectangular hole, that is, a sort of channel into which the carbonaceous substance is introduced for conversion. The charge is given a translatory movement through the furnace at a regular pre-arranged velocity. Two channels in line and perpendicular to the charge and ending in the heating chamber carry two carbon electrodes which extend close to the piece to be graphitized, and form with it a double arc. Notwithstanding the continuous movement of the charge, the arc can be maintained fixed by raising to a very high temperature the section of the electrode that it embraces.

Moreover, since the heating chamber is very slender, it can rightly be assumed that the temperature is sensibly the same throughout the chamber.

The translatory movement is imparted to the charge by means of cylinders or rollers driven by an electric motor. The electrodes and the charge pass through stuffing boxes where they enter the apparatus for the purpose of packing them tightly when it is intended to operate in a gaseous medium. The apparatus can be worked uninterruptedly, the rods to be submitted to the graphitizing process following each other continuously.

(b) Acheson or American Process

The method applied at Niagara Falls is based upon the following principle:

If a mixture consisting of amorphous carbon (coke, anthracite) and an oxide (alumina, silica, iron oxide) is heated in the electric furnace, there is formed a carbide capable of being dissociated in its turn into crystallized carbon or graphite, and an element set free by virtue of this dissociation (aluminum, silicon, etc.). The latter can be used in a reaction upon another quantity of amorphous coal and is thus able to continuously convert considerable quantities of the carbon into graphite.

Experience has shown that alumina is one of the most active substances employed for the graphitizing process. Next in order ranges iron oxides, manganese oxides, and silica (sand). In practice, these substances form the largest part of the ashes in amorphous coal, so that it is quite easy to change the latter directly into graphite; in fact, it is sufficient to submit the coal to the thermal action of the electric furnace, the amorphous carbon being previously ground and molded in the form of an electrode and the reducing current passed through it. For this operation, the strength of the current is fixed at from 30 to 40 amperes per square centimeter of electrode cross-section.

The furnace used for the manufacture of Acheson graphite electrodes is a parallelepiped of very large dimensions, i.e., its length is from 4 to 6 meters (13 to 20 ft.), its width 1.5 meters ($1\frac{1}{2}$ ft.), and its height 1.2 meters (4 ft.). The short sides of the furnace, A, are constructed of refractory brick having a total thickness of 50 cms. (20 in.). In the center of each of these walls there is an iron plate through which electrodes are passed. The interval separating the electrodes upon the same side of the apparatus is filled with graphite dust thoroughly compressed. The current is supplied on both sides of the furnace through heavy cables directly connected with the iron plate.

The manufacture of the electrodes is begun with the grinding of the mixture of coke and oxide (oxide of iron, etc.), or simply of anthracite rich in ash. The mass obtained is placed in the electric furnace between the electrodes mentioned above, and the electric current reduces the oxides to carbides which dissociate, leaving the carbon of the electrodes in graphitic state. The phenomenon proceeds further and further until eventually the entire mass is converted into graphite. The impurities enclosed in the mixture originally used are absent in the finished material, for it is just these that serve for the production of the catalytic phenomenon, and they volatilize at once.

Starting from anthracite containing 6 per cent ash, Acheson claims that he is able to make graphite electrodes having no higher ash content than 0.033 per cent.

In electrosiderurgy, because of the smaller contact surfaces and the greater resistance to oxidation of graphite electrodes, they would seem to be preferable to electrodes made of amorphous carbon with a binder, and baked.

Hence, in a great number of cases graphite electrodes offer real advantages; and with the further progress in electrometallurgy it is to be supposed that a great number of metallurgists will eventually come to make their own graphite electrodes. To do this

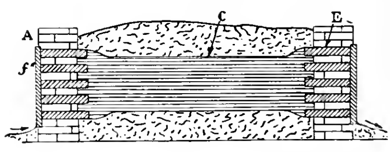


Fig. 4. Acheson Furnace for Manufacturing Graphite Electrodes

economically it would be profitable to utilize a part of the water power which is otherwise wasted. For instance, the supplementary power available during very high head periods could be used for graphitizating a stock of electrodes to cover the whole annual demand. This undoubtedly would mean an appreciable saving.

(B) Properties and Utilization

The physical properties of electrodes greatly influence their performance in actual use. Particular attention should be given to specific weight, mechanical strength, sonority, hardness, density, and electric and thermal conductivity. Their industrial value depends primarily upon the purity of the raw materials entering into their manufacture and the fineness of pulverization of these materials, the amount of agglomerant used, the mixing and drawing pressure, the baking, and finally the composition, but above all the ash content and the percentage of volatile substances.

Density, Hardness, State of Surface

The density of electrodes varies between 1.45 and 1.6. This property can be determined in a very easy manner, especially where electrodes of large dimensions are dealt with. It suffices to weigh them and to calculate the volume from the dimensions. The apparent density is found in this way the density of the carbon without taking into account the empty spaces separating the agglomerated grains. The density is influenced by the process employed in moulding and compressing. It is closely related with the mechanical strength of the electrode and permits, moreover, a rather correct evaluation of the degree of disintegration in actual use. The density can be determined with great exactitude from fragments or pieces which are weighed and whose exact volume is ascertained by means of a graduated sample if the specimen is nearly cylindrical in shape, or else by the aid of what we have called a densivolumeter* whenever the specimen is of irregular shape.

The real density, that is, the actual or true density of the substance without pores, yields more precise indications, particularly with reference to the purity of the composition of the electrode. The true density increases notably in inverse ratio to the hydrogen content of the carbon. The specimen to be measured is placed in a density flask in which a vacuum of 5 mm. of mercury is established to expel air bubbles. The precision of the result falls within the 0.5 per cent limit; in other words, the measuring exactness is one two hundredths.

Good electrodes are generally very hard. If they possess a special form they must be shaped prior to baking because it is difficult to work them with tools. Their surface should be as dense and smooth as is possible in order that good contact with the connections may be made. It is therefore necessary that the electrodes should be free from fragments, particles, and dust before they are fixed in the holders.

Mechanical Properties

Electrodes are liable to crack or break under the action of abrupt fluctuations in temperature. The degree of fragility gives an index and leads to the discovery of possible defects in the manufacture. Formerly, breakage constituted a frequent and serious cause of delays and inconvenience in operation; it was difficult to ascertain the breaking or cracking point, which mostly occurred at the threaded joints. But now it is easy enough to find out during the process of manufacture whether an electrode is cracked. For this purpose a rod is driven into the furnace on the opposite side of the electrode through a hole, and at the same time a hammer blow is struck upon the ends of the electrode. A typical sonorous sound indicates whether any break is caused by the shock. But when a rupture is produced it can easily be found in this manner and the fault remedied.

Graphite electrodes, though of less tensile strength than electrodes made of amorphous carbon, are less fragile. This is largely due to the high temperature to which they are subjected during manufacture, and to the method of cooling which is a kind of annealing process. This annealing greatly improves the thermal conductivity of the graphite and renders it more homogeneous. The practical effect of this is that temperature differences become balanced more readily and promptly in the interior of the mass of the electrode, and contractions and expansions are rendered more regular and uniform. The losses are thus considerably reduced, and the efficiency of the furnace in which such electrodes are employed is augmented.

Chemical Characteristics, Composition, Impurities

Inasmuch as carbon is a reducing agent it may enter into reaction with metallic oxides in fusion or in the incipient stage of fusion in the furnace. It is thus liable to cause unforeseen reactions. Moreover, it is apt to carbonize manufactured products to a greater or lesser degree. This is a property that is evidently undesirable and harmful in the

* See J. Escard "A Densivolumeter Useful for the Determination of the Density of Industrial Products," Comptes Rendus de l'Academie des Sciences, Vol. 154, May 6, 1912, page 1242, and Ann. de Chimie analytique, Vol. 17, No. 10, Oct. 15, 1912, page 368.

employment of carbon electrodes when used for certain products. In refining furnaces electrodes consisting of blocks of the metal that shall be refined are sometimes used, but when carbon electrodes are employed the operation of decarbonizing the cast is more or less complicated; because, first, the electrode may more or less carbonize the bath, while, second, the oxidizing slags may take away from the metal a certain amount of carbon. In practice, however, the oxidizing action of the slag is greater than the carbonizing action of the electrodes, and the desired degree of decarbonization is realized.

The impurities contained in the electrodes are sometimes very objectionable. Sulphur especially is liable to greatly harm the cast product. With the wear of the electrodes in electrosiderurgical operations, practically all of the sulphur passes into the molten mass, so that the sulphur contents may become as much as 0.005 to 0.006 per cent. Sometimes the sulphur admixture of the melt may exceed even 1 per cent, and this with the use of electrodes that supposedly are of good quality. An example is given in the analyses below, which were made on a lot of electrodes, No. 1 being made by a Swedish firm and No. 2 by a German manufacturer.

	No. 1	No. 2
	Per Cent	*Per Cent*
Ashes	3.96	2.80
Total sulphur	1.06	0.79
Total phosphorus	0.006	0.008

The composition of the ash was as follows.

	No. 1	No. 2
	Per Cent	*Per Cent*
SO_3	0.97	0.44
P_2O_5	0.37	0.63
SiO_2	42.00	37.80
Alkalis	0.45	1.21
CaO	10.20	6.08
MgO	2.16	2.62
Fe_3O_4	21.70	28.04
Al_2O_3	19.80	21.22
Mn_3O_4	0.38	0.52
Total	98.38	98.56

In spite of prolonged baking the electrodes contain from 0.25 to 0.40 per cent hydrogen; and in addition a volume of the same element due to the water that is absorbed subsequent to cooling, the proportion of water varying ordinarily between 0.25 and 0.35 per cent.

The analytical results of a large lot of electrodes made from amorphous carbon which were intended for the manufacture of aluminum follow:

		Per Cent
Combined carbon		97.11
Sulphur		0.49
Ashes	SiO_2	0.55
	Fe_2O_3	0.44
	Various	0.41
Humidity		0.35
Hydrogen		0.23
Various volatile substances		0.42
Total		100.00

Analytical figures by Mr. Ch. Louis for typical electrode compositions that are satisfactory are:

	Anthacite	Petroleum Coke	Retort Coal
	Per Cent	*Per Cent*	*Per Cent*
Combined carbon	95.0	98.0	94.6
Ash	2.5	0.2	3.8
Volatile substances	1.8	0.8	0.8

Thermal and Electric Conductivities

Carbon electrodes do not conduct heat as well as metals. For instance, a 0.5 meter electrode permits of maintaining between the two ends of the electrode a temperature difference of some 1500 degrees without having recourse to any artificial cooling means. According to various investigators, especially Hoering, the thermal conductivity of graphite would seem to decrease quite rapidly with rise of temperature, while the conductivity of carbon would appear to increase. For electrodes used at a working temperature of 1400 degrees, with one end being cooled by water circulation, we get the following comparative figures as a numerical expression of the thermal conductivity: 0.34 for graphite electrodes (made by the Acheson method) and 0.17 for electrodes made of amorphous carbon, copper having been used as the comparative unit or standard.

Carbon, furthermore, does not conduct electricity as well as metals, but in contradistinction to the latter its electrical conductivity increases with increase of temperature. This is an interesting property because it permits of raising the current carried by a carbon electrode without the resultant heating becoming excessive. In a cold state the resistivity of electrodes made of amorphous carbon ranges between 5000 and 7000 microhms per centimeter; but in a heated state it is considerably less. On the other hand, it grows with the proportion of the binder employed in the manufacture, while it decreases if the moulding pressure and the baking temperature are increased. Below are given the values of the specific resistance of various carbons used as electrodes, the figures referring to rods of one meter length and one sq. mm. cross-section:

	Cold	Hot
Acheson graphite . .	37.45	14.06
Acheson graphite .	21.90	15.56
Retort carbon	54.73	56.88
Ceylan graphite	56.84	6.09

The high electric conductivity of graphite electrodes allows of the application of greater current densities, or, what amounts to the same thing, of electrodes of smaller cross-section at equal currents. This is an advantage not only from the standpoint of greater economy of the material, but because of the lessened wear or diminution of the surface of the electrode exposed to the oxidizing action of the materials in the furnace. Hence, graphite electrodes show a longer life with their smaller dimensions.

The measurement of the resistivity of the electrodes is carried out regularly during the course of manufacture, the measurements being made on specimens taken from a lot. For this purpose various methods are in vogue. One, which is very simple, consists in sending a measured current through a definite length of electrode and determining the drop of potential between the two ends of the electrode. The resistivity is given by the ratio of the voltage and the strength of the current. Another method, which is more complicated, consists in measuring the resistance by the so-called double Thomson bridge. This method yields results of greater precision. It is well understood that the current used for these measurements must be rather small in order that heating of the carbon shall be avoided. The contact resistance can be minimized by hollowing the two ends of the testing electrode, and introducing into the holes small cups filled with mercury. It may be added that occasionally the resistivity of electrodes is reduced by inserting sheets or rods of metal along the axis of the electrodes. By this means higher conductivity and mechanical strength are obtained. (This matter is further described under the heading "Composite Electrodes" in Part II.)

Density of Current

The mean maximum current density used in electrodes for furnace work ranges between 3 and 4 amperes per square centimeter of cross-section (20 to 25 amperes per square inch). By the aid of artificial cooling this may sometimes be as high as 10 amperes per square centimeter (65 amperes per square inch). However, this constitutes the upper limit which cannot be exceeded by any means with ordinary amorphous carbon electrodes in continuous working. But graphite electrodes are capable of carrying currents up to 20 amperes per square centimeter. Hence, they are extremely serviceable in furnaces in which very high temperatures are to be reached; in other words, where operations require large power at small capacity.

The limiting current density which an electrode is able to withstand is related with the mechanical pressure applied in its manufacture. This pressure causes great differences in the values of the resistivity, owing to the difference in the proximity of the carbon molecules.

(To be continued)

Hardness of Soft Iron and Copper Compared

By F. C. Kelley

Research Laboratory, General Electric Company

The following record of experiments is of commercial value in that it shows that by the electric furnace ingot iron can be annealed to such a degree of softness as will permit of this material being substituted for copper in many of the cases wherein copper is now employed on account of its available soft characteristics —Editor.

The experiments described in this article were undertaken to determine how soft the purest grade of commercial iron produced in this country can be made after proper annealing, and how its hardness compares with that of copper.

The materials tested were American ingot iron from two different manufacturers (sheet bar material was $\frac{5}{32}$ in. thick) and ordinary cold rolled copper (two different thicknesses, $\frac{3}{4}$ and $\frac{5}{8}$ in.).

The following are the analyses of the two makes of American ingot iron tested, the iron having been determined by difference.

	No. 1	No. 2
Fe (By difference)	99.915	99.908
C	0.05	0.06
Mn	0.02	0.02
Si	trace	none
S (Gravimetric)	0.010	0.010
P	0.005	0.002

The hardness tests were all made by the standard Brinell method, the load applied in all tests being 500 kilograms and the diameter of the ball being 10 millimeters. Two different impressions were made upon each sample for check purposes.

The iron was subjected to eight different treatments as follows:

(1) A sample of the iron as received unannealed in sheet bar was first tested.

(2) A commercial factory annealing was given to another sample wherein the temperature was held at 765–775 deg. C. for about 8 hours in a closed pot.

(3) The factory-annealed sample (2) after being tested was reannealed in hydrogen at 900–950 deg. C. for three hours.

(4) Another set of samples were annealed in hydrogen at 900–950 deg. C. for three hours without a previous factory anneal.

(5) The iron subjected to vacuum treatment was annealed at 1000 deg. C. for about two hours.

(6) Samples were enclosed in a copper tube stoppered at each end with a copper plug so as to make it nearly air tight. This tube was placed in a closed electric tube furnace and annealed at 950 deg. C. for 3½ hours.

(7) A hydrogen-annealed sample from the fourth method of treatment was rolled from 0.312 to 0.208 in., or reduced to two thirds of its original thickness.

(8) A piece of the original sheet bar as received was given the same treatment as samples in the seventh method of treatment.

The second method of treatment is one at 765 deg. C. for 12 hours in a furnace heated by oil.

The third and fourth methods of treatment, called Ruder's anneal, produced the best results. This was carried out in a resistance furnace consisting of a porcelain tube wound with platinum ribbon. The tube is enclosed in a steel casing containing aluminum oxide for insulation. The hydrogen was dried and highly purified.

The fifth method of treatment which employed vacuum annealing and gave the next best results, was done in the Arsem vacuum furnace, diagrams of which are given in Fig. 1. The Arsem furnace consists of a water- and air-tight casing containing a graphite grid or helix gripped in water-cooled copper terminals and enclosed by a graphite screen.

Both the hydrogen and the vacuum methods have been previously described by Ruder, particularly in connection with their

TABLE I

Iron	Brinell Hardness No. 1	Brinell Hardness No. 2
(1) Unannealed as received in sheet bars	97.6	95.2
(2) Factory annealed	79.4	80.0
(3) Factory-annealed sample reannealed in hydrogen	57.8	63.0
(4) Hydrogen annealed	62.2	61.0
(5) Vacuum annealed	62.2	65.8
(6) Annealed in closed copper tube	66.6	66.0
(7) Cold rolled to two thirds of its original thickness after a hydrogen annealing	95.7	95.7
(8) Cold rolled as received to two thirds of its original thickness	110.5	112.5

great beneficial effect upon the magnetic properties of commercially pure iron and alloys. Their effect is not only an annealing but also a large reduction of its impurities present, such as oxygen, carbon, sulphur, and phosphorous.

The sixth method of treatment consisted of inclosing the iron samples in a copper tube, closed at each end by a copper plug, and then inserting the copper tube into the furnace with the porcelain tube wound with platinum. This porcelain tube was also stoppered at each end. This is called a close anneal.

The results of the two Brinell hardness tests are given in Table I.

It is of interest to know that this hydrogen or vacuum annealed iron may be whittled with a jackknife as easily as commercial copper.

Four different methods of treatment were tried on the copper as follows:

TABLE II

Copper	Brinell Hardness	
	No. 1	No. 2
(1) Unannealed copper bar	82.2	79.2
(2) Unannealed copper hammered to two thirds of its original thickness	87.4	96.8
(3) Commercial annealed copper	40.6	40.2
(4) Commercial annealed copper rolled to two thirds of its original thickness	89.4	92.6

of the hammer was not parallel with the block upon which the copper was hammered. To check the result, a piece of copper was rolled so that the reduction would be uniform, and the results are nearly the same.

The following conclusions may be drawn from these experiments:

American ingot iron subjected to a hydro-

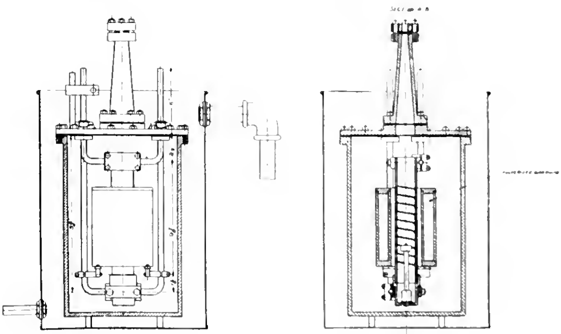


Fig. 1. Small Vertical Vacuum Furnace

(1) Commercial copper bar as received was tested without any treatment.

(2) Commercial copper bar 5/8 of an inch in thickness was hammered cold to two thirds of its original thickness.

(3) A piece of copper bar 3/4 of an inch in thickness was annealed in a commercial gas furnace to about 600 deg. C. so that it was dead soft.

(4) A piece of the same bar after receiving a commercial annealing was rolled to two thirds of its original thickness.

The Brinell hardness values in Table II are the results of the foregoing treatments:

The sample which was hammered (2) was hit by a steam hammer and shows that it received a little more working in one spot than another, due to the fact that the face

gen annealing is of a hardness about 20 points higher than that of dead soft copper; and the vacuum process is nearly the equal of the hydrogen process.

If annealed copper and annealed iron are each worked to produce a one third reduction in thickness, the hardness of copper increases over 100 per cent of its original hardness while iron increases only about 60 per cent.

The range of hardness between dead soft copper and commercial copper as received is between 40 and 80; while the range of hardness between hydrogen annealed ingot iron and the commercial material ranges between 60 and 95.

Carefully annealed ingot iron could be used in many places where copper is now used because of its softness.

Incandescent Lighting in War Time

By G. H. Stickney

Edison Lamp Works, Harrison, N. J.

and

T. W. Moore

General Electric Company, Atlanta, Ga.

This war is a twenty-four-hour-a-day business and, with but few exceptions requires illuminants for night operations. Illuminating engineers, lamp manufacturers, and central stations have enthusiastically enlisted their services to produce maximum results at the highest efficiency and economy. The following résumé of the features concerning incandescent lighting in war-time demonstrates that this branch of lighting, when properly conducted, is an immense factor in successfully carrying on the night work of the business of war. This article was presented as a paper at the 1918 Convention of the Tri-State Water and Light Association of the Carolinas and Georgia.—Editor.

The war has imposed upon the nation many readjustments in order that the maximum effort may be expended to bring this conflict to a prompt and successful conclusion. It is apparent that such rapid adjustments may involve some injury and perhaps injustice. Since unnecessary confusion detracts from the national resources and unity, it is especially important to avoid it wherever possible. Free discussion of war-time lighting questions is a means of securing a better understanding of the problems in this field and thus of contributing to the winning of the victory.

The first duty of a lamp or equipment manufacturer is to provide the necessary apparatus for the use of the military arms. The record of accomplishments in this connection would be quite interesting and would indicate results of which the lighting men might well be proud. It is obvious, however, that it would not be proper to treat of such development publicly. This article has therefore been directed rather toward those things which can be advantageously applied in the industrial and other activities which constitute what has been aptly termed "the back of the sword."

The practice in lighting is variously affected by the conditions required of lighting itself (such as fuel conservation measures and restrictions on central stations), and indirectly by those required of all other activities with which lighting is employed. Some of these requirements may be classified as follows:

(1) Necessary manufacturing, transportation, and other activities must be conducted as efficiently, speedily, and safely as possible in the face of a shortage and high cost of human effort, capital, and materials.

(2) Luxuries must be restricted so that effort and material can be diverted toward more necessary enterprises.

(3) Unnecessary waste must be eliminated.

Effectiveness of Good Lighting

The large manufacturing corporations of the country have generally come to appreciate the effectiveness of good lighting in speeding production and improving the quality of output. Many smaller concerns not having engineers and specialists available for the analysis of lighting and other operating factors have been more conscious of the *direct cost* of lighting, than the *indirect economics* resulting from proper lighting. While these economics were important in peace time, they have acquired new significance under the heavy demands for munitions and other manufactures, especially since it has been necessary to operate overtime, and in many cases both day and night.

It has been the observation of lighting experts that better illumination is demanded for all-night work than where the artificial lighting is used for an hour or two a day. This is no doubt due to the strain of the long working hours, as well as to the impracticability of rearranging the work so as to perform only simpler operations under artificial lighting.

It has recently become necessary to train new operatives in large numbers. Such employees really need better light than experienced workmen with whom the operations have become more or less mechanical.

Figures taken from a considerable number of typical manufacturing plants have indicated that the entire cost of good artificial lighting is on the order of one per cent of the wages of the workers affected, while the increased cost of providing good illumination to replace poor lighting, now in use, is very much less. On the other hand, good lighting can make a very considerable increase in production. An example of this was recently reported by Mr. P. S. Millar from data furnished by the Commonwealth Edison Company of Chicago. In this instance the illumination, which was of a value ordinarily considered adequate, i.e., 4 foot-candles, was tripled. A record of production on eight different processes showed an average increase of 15 per cent.

If we take into account economy of materials and machines, as well as overhead costs, in addition to the direct labor elements, it is hard to see how anyone can justify poor lighting as anything short of gross extravagance.

Fig. 1. Night Photograph of a Row of Warpers Well Illuminated by 75-watt Mazda C Lamps in Deep Bowl Steel Reflectors Hung Over the Beam and the Creel. Work under such can be carried on effectively, independent of daylight conditions. With good illuminations, the shop is perforce clean and safe. Employees are contented and production is kept at a maximum

Industrial Lighting Codes

While safety of employees does not demand as powerful an illumination as does economic production, it is nevertheless of first importance. Good lighting is probably the most effective precaution for the prevention of accidents. In some processes, poor lighting is a common cause of failing eyesight, which impairs the ability of employees just when experience had qualified them to render their most effective service. So serious have these conditions become, that several states have taken steps to protect employees through regulations.

Codes of lighting for factories, mills, and other work places are now in force in New Jersey and Pennsylvania, while similar regulations have been issued in Wisconsin, New York, and Ohio, and are now under consideration. The Bureau of Standards, acting in conjunction with Safety Inspectors, has adopted such a code for all federal establishments. The Divisional Lighting Committee, a sub-committee under the Advisory Commission, Council of National Defense, has adopted a code to be recommended in other states. All of these codes are quite similar in their requirements, and are based upon the one prepared by the Illuminating Engineering Society. They provide merely for safety of employees, and not for efficient production, the latter being beyond the scope of the laws under which they are authorized.

It is probable, however, that many manufacturers, in studying the lighting question in this connection, will come to appreciate the economic advantage of good lighting and provide intensities much higher than can be enforced under a safety provision.

Protective Lighting Necessary

The enemies of this country are well aware of the importance of manufacture and transportation in winning the war. Hence, we are encountering a persistent and a more or less organized effort to destroy plants, bridges, tunnels, harvests, and other materials. The destruction is accomplished by underhanded methods, mostly under the cover of darkness.

Mr. Edmund Leigh, Chief of the United States Bureau, in charge of Plant Protection, considers good watchmen, good lighting, and good fencing the three essentials of protection. Light is necessary to render either watchmen or fence effective. Good lighting enables a small number of watchmen to detect intruders over a large area, and furthermore it discourages attempts at unlawful entrance.

The purpose of protective lighting is to make visible the movements of persons entering a plant, approaching important works, or otherwise acting in a questionable manner. To prevent entrance, approaches are illuminated and a zone of light provided around the boundary covering all possible points of entrance and all vulnerable places.

Since it is always possible that enemies may enter as workmen, dark spaces and shadows within a plant, which may serve for concealment, should be eliminated. While it is desirable to illuminate in such a way that the watchmen may be inconspicuous, this feature is ordinarily subordinate to the question of rendering intruders clearly visible.

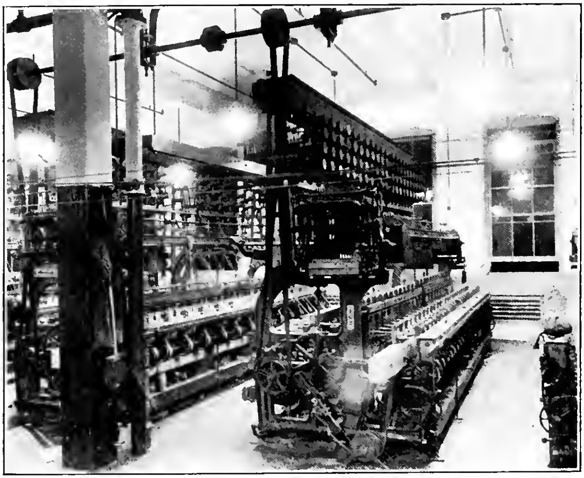


Fig. 2. Semi-indirect Lighting in Industrial plants is Comparatively New. It has certain inherent advantages, such as absence of glare and even distribution of light. In this particular instance, it is especially well suited. The high mechanism of the tape looms could not be rendered clearly visible unless some lighting system, such as this, which gives excellent diffusion, was employed. Where the indirect lighting systems are used, it is essential that the ceiling be light in color and accumulation of dust and dirt minimized

Protective lighting is relatively new, and the variety of conditions to be met is so great that the details of practice have not yet been very fully standardized. The lighting should be planned with reference to the physical arrangement of the plant, the fencing, location of guards, and system of patrol. The best lighting so far installed has employed street lighting units, dome and angle steel reflectors, floodlights, and searchlights.

It is common practice to use two or more types of units to meet the various conditions about the same plant. The early installations employed floodlighting almost exclusively on account of its adaptability and the quickness with which it could be installed. More recently, the tendency has been toward the use of other types of incandescent lighting equipment, which is often more efficient, available in a wider range of sizes, and can be arranged to minimize glare. For some conditions floodlighting has special advantages, particularly where it is desirable to provide a directional light at quite a distance from the lighting units. Glare itself can often be utilized to advantage.

Fig. 3. The Yard of an Industrial Plant Well Illuminated for Protection by Floodlighting Projectors, Renders Every Portion of the Area Clearly Visible and No One Can Cross Without Being Seen by the Watchman

Besides the ordinary methods of lighting, silhouette lighting has proved particularly economical where large areas must be covered. For example, where the intruder is likely to cross a large level space, instead of lighting the entire area, a whitewashed wall, which will serve as a background, may be lighted, when the conditions are such that anyone moving would be seen in outline against the lighted surface. As a matter of fact, silhouette vision is employed to a much larger extent in ordinary street lighting than is generally appreciated.

For indoor spaces, the practices followed for ordinary industrial lighting generally apply. The intensity need not be so high as is required for manufacturing places, but all deep extensive shadows should be eliminated by the removal of high objects which may obstruct the light, and by the design of the lighting system

The government Bureau of Plant Protection has made a thorough study of lighting problems and other features, and is well qualified to give and to secure advice as to methods.

Lighting Curtailment

During the past winter, the fuel shortage necessitated steps to economize in the consumption of coal and other fuels. Lighting experts have generally argued that efforts in this connection were directed toward lighting to a much greater degree than its importance as a fuel consumer warranted. Such movements, unless properly directed, are liable to produce conditions dangerous to life and limb and to slow down necessary production. Furthermore, it is possible that the complacency following a larger expected saving, which will not be realized, may prevent steps in other directions where real saving could be made.

There is always a tendency to propose that others make sacrifices, and it is to the credit of the lighting businesses that they accepted the problem patriotically. It is quite possible that this problem will arise next winter, so that it is important that the public and their representatives be made cognizant of the real determining factors

This subject is very ably treated in a paper on Lighting Curtailment recently presented by Mr. P. S. Millar before the Illuminating

Engineering Society. Any restriction should, of course, be made in such a way as to give the maximum advantage with the least injury. Lighting interests should willingly accept their fair share. Luxurious lighting, in common with corresponding luxuries,

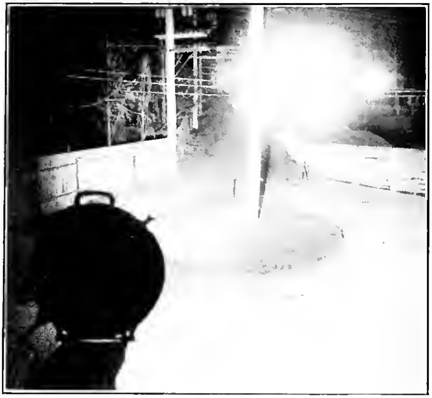


Fig. 4. A Floodlighted Alley or Passageway. One projector points directly down the path. The guard stands at the rear of the lighted unit in shadow. The brilliant light renders those approaching visible and yet prevents the intruders from seeing the guard

which make demands upon energy and materials, should share any necessary retrenchments.

Electrical advertising may have to be restricted along with other forms. There are, however, many forms of lighting, which are essential to the safety of workers and other citizens as well as necessary to production.

Protective lighting, whether in plants or streets, should be increased rather than diminished. The editor of the *Coal Age*, writing in the *Saturday Evening Post*, called attention to the fact that our enemies are in our midst rather than in the air, as in England, so that increased lighting rather than reduced is essential English reports show that the increase in the number of people injured in street accidents is greater than those from air raids. The tendency then is to provide more street illumination.

Reduced lighting in factories may not even result in fuel economy, as it results in lower output per ton of coal consumed for power and heat. It would be more logical to eliminate unnecessary industries and compel others to utilize efficiently their man-power and materials.

Elimination of Waste.

It goes without saying that waste should be eliminated yet, especially in our industries, inefficient lamps and equipment are still being used. Due to superior efficiency, Mazda lamps have very largely replaced carbon and Gem lamps, so that lamp manufacturers began to regard the latter types as almost obsolete. During 1917, however, the demand for these lamps could not have been met without sacrificing the production of Mazda lamps. It is recognized that there are a few applications in which lamps receive extremely rough usage, for which the carbon lamp is the more practicable, so it is necessary that this lamp be made available. On the other hand, observation of a large number of installations reveals the fact that carbon lamps are used to a considerable extent when properly designed lighting with Mazda lamps would not only result in a large energy saving, but often at a reduced installation and maintenance cost.

The increased demand for carbon lamps seems to be largely due to lack of intelligent planning in hastily constructed buildings to meet the rapidly increasing demand for certain manufactured articles. Such lighting may have been justifiable as a temporary measure, but increased production would in itself justify rearranging such installations with modern efficient equipment.

Important gains can be made by the use of modern reflectors and other accessories to insure effective utilization of light. Incandescent lamps, being renewable parts, are made to meet universal requirements and thus distribute light in all directions. A reflector redirects light and can be selected to meet the requirement of particular uses. It has the further function of eliminating or minimizing glare. A modern illuminants are too brilliant to be viewed with comfort, especially the more efficient ones. Unless shaded or otherwise diffused the glare renders the illumination less effective and in extreme cases causes accidents or eye injury.

To insure effective service from their product, lamp manufacturers have co-operated with reflector manufacturers in regard to design and construction. While a tin shade is cheaper than a well-built reflector, it is in the long run a false economy to use other than the best equipment.

Conclusion

In presenting this commentary on wartime lighting, the authors have endeavored to furnish a basis for further discussion. No attempt has been made to cover details of practice or developments. Lighting practice is treated in many articles and publications, including those of lamp manufacturers. There have not been many developments of lamps and reflectors—beyond the special apparatus for governmental service. Manufacturers of lamps and equipment have encountered the same difficulties as other manufacturers and have had many problems to solve in maintaining the quality of their product.

Until this war is won, no business will be on a firm footing. Patriotic duty and business stability both demand any sacrifice which will help to secure the victory.

Street Lighting with Reference to the Manufacturer, the Central Station, and the Municipality

By G. L. Thompson

Philadelphia Office, General Electric Company

The author discusses the street lighting problem from view points of the manufacturer, central station, and municipality. He shows that the rate of increase of improvement in lighting is not likely to be as great in the future as in the past, therefore the changes necessary to secure the latest type and highest efficiency will be less frequent. He states the difficulties confronting the lighting committees, reviews the advantages of large individual lighting units, and summarizes some of the most important points to be considered in the lighting of business centers, intermediate sections, and outlying districts of municipalities. The use of lighting units of highest efficiency is in compliance with the program of the Fuel Administration, as published elsewhere in this issue.—Editor.

The manufacturer of modern street lighting appliances can justly be accused of having changed standards frequently causing the purchase and use of lighting units which, through improvements, are so far in advance of equipments sold only a few years ago as to render the old devices unprofitable as well as inefficient to operate.

This condition was to be expected as time advanced approximately 20 years with the continued use of the old carbon arc and incandescent lamps before great improvements began to evolve. The start was made by metallizing carbon filaments and gradually working into tantalum and then tungsten. The progress was rapid in improving quality and reducing prices, bringing us to the present high Mazda quality.

While the manufacturers have made more rapid strides in the last five years it is not probable that this rate of improvement can continue, and it is reasonable to expect no great improvement in efficiencies during the ordinary life of a street lighting contract. It is therefore advisable to select the most suitable means of operation, and more careful thought should be given to the replacement of the many inefficient devices by such arc and incandescent units as are best adapted for the work required.

The central station stands between the manufacturer and the municipality. The duty of the central station is to obtain the best and most efficient appliances, and as it is selling light for street purposes it should give in quantity and quality the light best adapted to the various requirements. It should give all the light it can for the money paid as it is in its interest to operate at a high standard, thereby causing a general increase in business, affording protection to the community, and creating a feeling of good will which does not exist where indifferent or poor lighting is supplied.

A few years ago the street lighting load was considered to absorb a large part of the central station output, but in any active plant of today this load is but a small per cent of the total.

If this is the case, why not adopt a high standard of illumination and have it reflect to the good of the cause and receive such favorable comment as will justify favorable talk about it? Be on friendly terms with the Lighting Committee, make its members realize that it is your desire to supply the best you can, and that you will supply it for a compensation more reasonable than that asked of ordinary customers, in consideration of franchise rights, privilege, etc.

The municipality is the most interested. Lighting for safety is an important item of its expense, and ordinarily the payments for this service are far below what good results justify.

Lighting Committees are frequently caused to be indifferent as appropriations may have been cut, and almost without exception they claim to have no money in hand, none in view, and are, therefore, forced to be contented with lamps too low in candle-power, or placed too far apart, either of which is not to the best interests of the community.

This condition can be easily remedied by proper appropriations, and what taxpayer would notice, or regret, a partial per cent of increase in tax, providing an equitable return is given? If good lighting is once obtained who, except a criminal, would want poor or even indifferent lighting?

Acknowledging that a rearrangement is justified, what is the proper course to pursue? This can best be determined by co-operation. Reference will now be made to some of the plans necessary for reaching the results desired.

There are three main conditions to meet. First, the business center; second, an intermediate section; and third, the outlying district. The business center being the most important part of a municipality justifies, by taxation, an entirely different class of lighting to that which should be supplied in other sections.

There are two modern light sources for consideration, the arc and the incandescent, both of which can be obtained in high candle-power units, and by using diffusing glassware the light is distributed not only to illuminate the center of the street but to reach to a height of several stories on the prominent buildings located on either side.

A business center justifies placing the lamps sufficiently close to enable the use of diffusing glassware. A smaller number of larger units properly spaced is more economical than the converse. The lighting units may be placed singly on some one of the many designs of iron poles suitable for the work, or a pendent type of fixture may be selected.

It has been customary in the center of many cities to locate five-light clusters, this having been considered ornamental; but the extensive improvement in the lamp justifies the use of one large light for various reasons.

First. There is a factor of about 30 per cent obstruction to light, due to what is called interference, when five-light clusters are used.

Second. A smaller current consumption will be required.

Third. It is much cheaper to install the single unit than to buy ornamental posts for the five-light clusters.

Fourth. Where five-light clusters are installed there is a large glare of glassware, as the globes seem to stand out prominently, while with the single standard the fixtures are hardly noticeable and do not detract from the appearance of the buildings or streets.

Fifth. Arrangements can be easily made by which the present five-light clusters can be changed and a neat ornamental top obtained using a single diffusing globe, well ventilated and drained.

If for any reason it is not desirable to use the modern arc lamps the Type C Mazda lamps may be used on similar ornamental posts or suitable pendent fixtures. By various combinations of globes, reflectors, or refractors, many combinations of quantity and quality are obtainable.

To a municipality the spacing of lamps is an important consideration, and justifies the engineering advice of those who specialize and are by experience able to determine the quantities of light and apply the best to the various needs.

A size of unit should be selected to give the quantity desired by proper spacing. The writer has seen fixtures located 50 feet apart on each side of the street producing an overdone effect and then not obtaining good lighting.

For the intermediate section or in smaller cities where a high intensity is unnecessary the 4-ampere luminous lamps with high efficiency electrodes will give good results. A slightly lower cost can be obtained by using a long life electrode, but this does not give as great a quantity of illumination as does the high efficiency electrode. The intermediate sizes of Mazda units are also of advantage and with these the illuminating standard can easily be made higher than with the 6.6 or 7.5.-amp. series alternating carbon arc lamps many of which are inefficiently used today.

With clear glass and reflectors the maximum illumination from luminous arc lamps is at an angle of about 10 degrees below the horizon which is especially effective where the lamps are spaced long distances apart. A refractor would still increase the foot-candle illumination at a given point, say 150 feet from the pole, but where lamps are comparatively close the refractor is unnecessary.

If in the intermediate section there are a number of stores of prominence, the lamps should be more closely spaced and equipped with diffusing globes, so as to bring into prominence the business sections.

The outlying districts probably require more thought and consideration in accomplishing economical results than either of the other sections referred to.

On a main thoroughfare leading to a center, the best arrangement is to extend lighting similar to that considered best adapted for the intermediate. For streets of lesser importance there is a variety of street lighting brackets and suspensions which are easily installed and are reliable in operation when they are amply insulated between the lighting fixture and the lamps. These lamps for series circuits are rated 60, 80 or 100 candle-power, and considering the fact that the 100-candle-power lamp now consumes about the same wattage as that formerly obtained in the 25-candle-power carbon lamp, it would be advisable to use a lamp of this rating as frequently as possible and the smaller ones at only the insignificant points. Where the sections are closely built up, effort should be made to locate larger units than in less thickly populated sections.

If the lamps are for general street illumination and are placed 400 to 500 feet apart, refractors will materially assist in bringing about the good results desired and will produce a silhouette effect which is extremely essential where automobile and other traffic is heavy.

It can safely be stated that the standard of illumination today is very low in comparison with the improvements which have been effected in the last few years, and therefore the manufacturer should co-operate with the central station and both with the municipality to raise the standard.

Tendencies in Textile Mill Illumination

By A. L. Powell

Edison Lamp Works, General Electric Company

The need for close and constant inspection of the product of textile mills demands high intensity illumination, and the output and quality of the manufactured goods are, therefore, directly affected by the character of the lighting installation. Before the advent of the present high efficient Mazda and arc lamps, it was customary to use carbon lamps for local lighting or else the inefficient enclosed arc lamp spaced at long intervals. The excellent illumination that can be obtained by use of Mazda C lamps with proper reflectors is strikingly shown by the illustrations.—Editor.

Every indication points to the growing use of general lighting in textile mills, with a marked tendency toward the indirect methods of lighting for work requiring close visual application wherever the character of the ceiling is such as to give efficient reflection.

With the indirect types of lighting, the reflecting power of ceilings is of prime importance. Not only should the ceilings be free from obstructions, but they should be finished with a white paint which does not depreciate to any extent with age. Moreover, all glassware, ceilings, and other reflecting surfaces must be kept clean, so as to utilize their reflecting and diffusing powers. By using the most economical lamps, such provisions economize and improve the illumination to an extent which justifies their predominance under the old law of the survival of the fittest.

The illustrations are night photographs of textile mills illuminated by the general system. A few years ago it would have seemed quite out of the question to provide satisfactory light by this method. The pictures, however, speak for the uniformity and absence of annoying shadows. The mills operate successfully under such lighting, and lamp costs are reduced as well as the power consumption.

It is always of interest to the engineers of an industry to watch the changes in practice which take place as new developments in electrical appliances come into general use. Lighting devices, or lamps, have undergone startling improvements more rapidly than any other class of equipment. As a result lighting practice has been constantly varying, sometimes going from one extreme to the other.

It is the duty of the skilled illuminating engineer to watch the progress and attempt to foretell the general nature of future developments. He must act as a balance

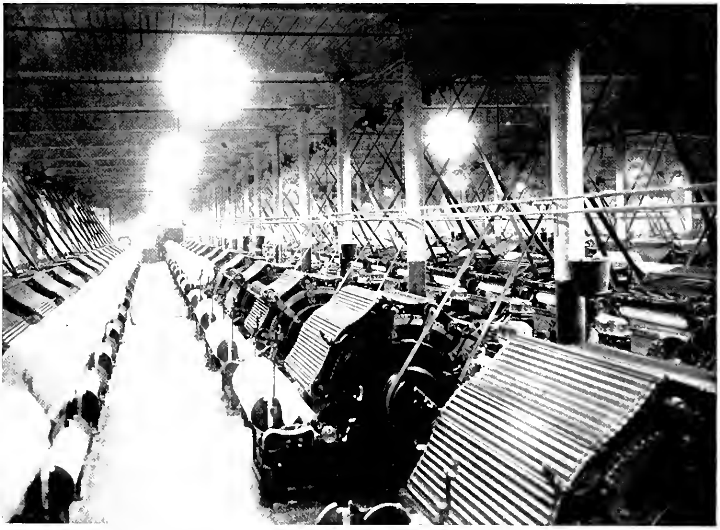


Fig. 1. Night View of a Card Room in a Southern Cotton Mill. This is lighted by 100-watt Mazda lamps in deep bowl enameled steel reflectors hung 14 ft. high and spaced 12 by 22 ft. One outlet is provided in each bay, staggered. All parts of the machine are clearly visible as well as overhead shafting and belting. Under these conditions the room is much safer than when a few spots only are brightly lighted

Fig. 2. 100-watt Mazda Lamps in Deep Bowl Aluminum Finish Steel Reflectors Furnish General Lighting for these Pickers and Breakers. Lamps are hung 15 ft. above the floor and one outlet is provided in the center of each 20-ft. bay

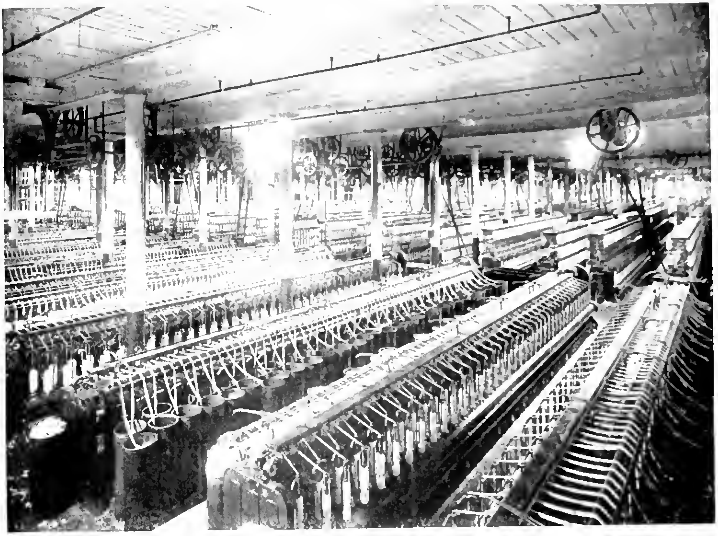


Fig. 3. Slubbers and Roving Frames Well Illuminated by a General Lighting System. 500 watt Mazda C lamps in dome shaped enameled steel reflectors are placed close to the 18 ft. ceiling on centers 24 by 33 ft. One can work efficiently in any part of the room.

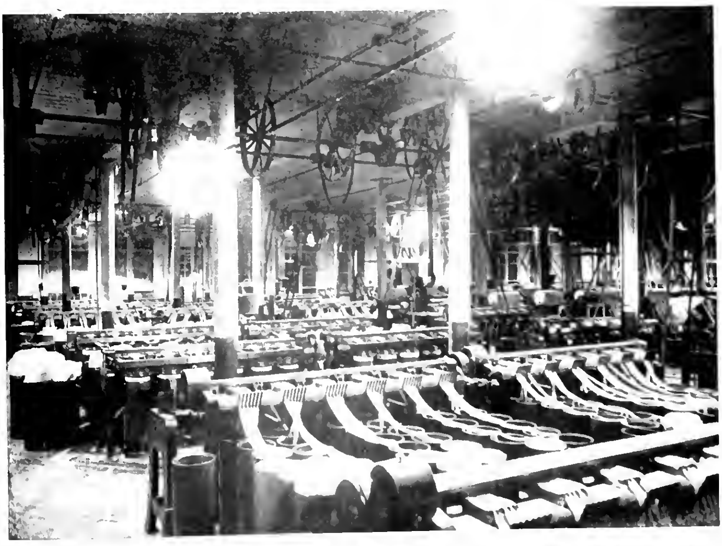


Fig. 4. The Drawing Frames in a Southern Cotton Mill . . That Appear Ill[illegible] Mazda Lamps in Deep Bowl Enameled Steel Reflectors. These are 16 ft. above [illegible]

wheel and bend his energies to directing the light users along lines which will produce the best results. The variations which have occurred in the field of lighting under consideration serve as an excellent illustration of the principles outlined above.

It was not many years ago that the only suitable light sources for textile mills were low candle-power, inefficient carbon lamps, and relatively high-wattage enclosed arc lamps. This resulted in two methods of lighting which were quite different.

The plant using incandescent lamps had to rely entirely on so-called local lighting, where lamps are placed close to the work. With this system operators lose time in moving the lamps about. There are spots very brightly lighted and intervening spaces are in comparative shadow. Reflectors become dirty through handling and are often omitted or misplaced, so that bright light sources are directly in the field of view. Nevertheless, on account of the inefficiency of the lamps, local lighting was the only thing feasible if a sufficiently high intensity was to be secured at the work.

Where enclosed arc lamps were employed, they were hung as high as possible and spaced rather widely. This lamp was none too efficient, and economic considerations prevented lamps being placed as close together as desirable for producing the most effective results. The travel of the arc precluded the use of reflectors which could accurately control the distribution of light. In some instances a combination of general illumination from arc lamps and local lighting with incandescent lamps was used.

About eight or nine years ago the Mazda lamp came into general use in industrial plants, and in textile mills a new method or practice in lighting developed. This was known as group or localized general illumination. The effect of the old practice with carbon lamps was still quite noticeable, for only the small sizes of Mazda lamps were extensively employed. Forty- and sixty-watt lamps in deep bowl steel reflectors were hung from 8 to 10 feet above the floor and localized with reference to important working points. Of course, this hanging height kept lamps out of reach of the operatives and allowed sufficient spread of light so that the aisles and surrounding spaces were illuminated. Localized general lighting was certainly a big step forward and still is particularly advantageous for some exacting processes.

A short time ago the Mazda C lamp was placed on the market and high candle-power sources of very high efficiency became available. A point of special interest in this connection is that in general the larger the lamp the greater its efficiency as measured by specific output.

Improvements in mill construction paralleled these advances in lamp development and we now find the modern mill with high ceilings and less overhead obstructions. Individual or group machine drive has replaced line shafting so that conditions are much more favorable to a wider spacing of lamps. Practice seems to be tending toward general illumination.

General illumination implies a symmetrical spacing of outlets with regard to the building structure or bays. It is of such a character that the position of machines can be varied at will and yet they will remain well illuminated. It approaches daylight in character and uniformity. The advantages of general lighting are, of course, the opposites of the disadvantages of local lighting. Fewer outlets are required, reflector equipment does not depreciate through constant handling, the room is cheerful and safe, the workmen lose no time adjusting the lamps, and the general appearance of the plant is far more business-like than when drop lamps hang over each machine.

Before the introduction of the Mazda C lamp direct lighting was almost universal in industrial plants. Now, with the higher efficiency of lamps and the more universal appreciation of the good qualities of indirect and semi-indirect lighting, these systems are being installed in a number of mills.

United States Fuel Administration's Program for Abolishing Inefficient Types of Incandescent Lamps

By Substituting Highly Efficient Lamps for the Carbon and Gem Types, a Saving of One Million Tons of Coal a Year is Estimated

The United States Fuel Administration, which for some time has been considering the best means of discouraging the use of inefficient incandescent lamps, has announced its policy which is based on a program drafted and presented by a committee of the lamp manufacturers of the United States.

On July 15th, at the request of the Fuel Administration, a meeting of incandescent lamp manufacturers was held to consider the best means of eliminating the wasteful and inefficient use of electric energy for lighting, in order to reduce the consumption of fuel as far as possible. At this meeting a committee was appointed to investigate the matter and draw up a set of recommendations to be presented to the United States Fuel Administration. At a meeting of the committee on July 25th, the following program was presented and unanimously adopted, and the chairman was instructed to submit it to the Fuel Administrator.

CONSERVATION PROGRAM

The following program is recommended to the United States Fuel administration:

1. The elimination of unnecessary types of standard carbon lamps and of carbon lamp types for special applications as follows:

The standard 60-watt multiple carbon lamp 100–130-volt range.

The standard 20-watt S-14 bulb multiple carbon lamp 100–130-volt range.

The 120-watt standard multiple carbon lamp 100–130-volt range.

The complete elimination of standard 30- and 60-watt round bulb multiple carbon lamps, and all other types of 100–130-volt range multiple carbon lamps with standard base used for decorative purposes.

2. The complete abandonment by central station companies of the installation and renewal of carbon incandescent lamps of all sizes, and discouragement of their use by their consumers and the public for any use or application for which tungsten lamps can be substituted; this policy to go into full effect not later than September 15, 1918. (Postponed date, October 15th.)

3. The gradual abandonment of the installation and renewal of metallized filament "Gem" lamps of all sizes by the central station companies and discouragement of their use by their consumers and the public for any use or application for which tungsten lamps can be substituted.

Under special and unusual conditions where it is absolutely necessary to use lamps with exceptionally robust filaments owing to rough handling or excessive vibration, the use of carbon lamps is recommended so that the metallized filament "Gem" type may be completely eliminated. This policy to go into full effect not later than November 15, 1918. (Postponed date, December 1st.)

4. It is recommended that the use of considerable numbers of the smaller sizes of lamps for commercial and industrial applications be eliminated where it is practicable to substitute for them large single gas-filled lamps of highest efficiency in a smaller number of lighting units.

5. It is recommended that the use of vacuum tungsten lamps in sizes of 100 watts and over be eliminated and whenever practicable gas-filled tungsten lamps of highest efficiency substituted therefor.

6. It is recommended that electric light and power companies employ no differentials in their price schedules for the sale or renewal of lamps which may tend to encourage the use of larger sizes of lamps rather than smaller sizes.

7. It is recommended that all manufacturers of carbon and metallized filament "Gem" lamps insert with each standard package of such lamps shipped by them a printed notice directing the attention of the user of the lamps to the fact that the particular lamps in the package should be used only in locations where it would be impracticable, because of excessive vibration and rough handling or for therapeutic and heating purposes, to use satisfactorily a more efficient type of lamp.

It is recommended that the manufacturers use the following standard form for such notice:

> Complying with the request of the United States Fuel Administration, you are asked not to use, or advise the use of, the lamps in this package in such locations and under such service conditions where a more efficient type of lamp would be satisfactory.
>
> Signed
>
> Manufacturer's Name

8. It is recommended that where the United States Fuel Administration promulgates these regulations it should call the attention thereto of the public service commissions and other regulatory bodies, state and municipal, and should urge that where a public service corporation in order to comply with the terms thereof has the cost of lamp renewal service under the contracts with its customers substantially increased thereby, the public service corporation be permitted either to collect from its customers so affected the increase in the cost of the lamp renewal service or discontinue the furnishing

of free lamp renewal service and, where practicable under present conditions, make therefor an appropriate adjustment.

It is recommended that the central station companies be requested to urge upon their customers and the general public in their advertising in the daily press, company house organs, and in all promotion literature the importance of selecting lamps of sizes which do not provide an amount of illumination beyond what is strictly necessary, the exercise of due care in extinguishing all lamps which are not needed and the elimination of all extravagant and wasteful use of light, as a measure of fuel conservation.

10. It is recommended that a pronouncement be prepared and submitted for the approval of the United States Fuel Administration to be distributed to all of the electric light and power companies of the United States, through the facilities offered by the National Committee on Gas and Electric Service, calling attention to the urgent necessity of fuel conservation and inviting the co-operation of all users of electricity, for light and power purposes, to a full compliance with the conservation program as finally approved by the Fuel Administration.

It is recommended that in the promulgation of the program by the United States Fuel Administration the co-operation of the manufacturers, electrical supply dealers, and electrical jobbers be invited in order to secure the widest possible publicity for the conservation measures proposed, reaching in these several ways every class of lamp user through all of the production and distribution channels.

11. It is recommended that the United States Fuel Administration communicate the program as finally adopted to the various government departments making extensive use of incandescent electric lamps, such as the Shipping Board, Army, Navy, Treasury Department, etc., and invite their co-operation in conforming with the program to the largest practicable extent.

Statement of Conditions Involved

A general statement in regard to the foregoing program is included in the report, as follows:

"Many electric light and power companies throughout the country furnish incandescent electric lamps of the metallized filament "Gem" type, and to a very much less extent of the carbon type, as free renewals within the cost of current or at a small extra charge either for the first installation of the lamps or for subsequent renewals. The conditions of rendering this service are set forth in the rate schedules of the companies as filed with the public service commissions or other regulatory bodies, state or municipal, and they are often incorporated in the franchise provisions, or in the street lighting contracts between the utility companies and the municipalities.

"A change in the lamps furnished under these contracts from carbon or "Gem" lamps to tungsten lamps, or from large sized vacuum tungsten lamps to gas-filled tungsten lamps, in order to comply with the program above outlined will often result in an increase in the cost of the service. It is impossible for the electric light and power companies to bear this increased burden of cost of service at this time when nearly every public utility throughout the nation is suffering seriously, due to impaired revenues or increased cost of service, or both, due to war conditions.

"It is, therefore, but fair to the utilities where the substitution of lamps of higher efficiency for those of lower efficiency results in an increased cost of lamp service to their customers in order to comply with the recommendations of the program, that the public service corporations should be allowed to recoup themselves for the actual increased cost of service under the new conditions, and the United States Fuel Administration should issue a definite recommendation to this effect.

"Should it be deemed inexpedient to make an extra charge to the customer to effect the change if the existing contract provides for the furnishing of lamps of the types eliminated under the program, the public utility corporation should be allowed to discontinue the supply of free lamp renewal service and, where practicable under the conditions in which the companies find themselves, an appropriate adjustment should be made therefor.

"It is considered impracticable to make a broad recommendation in regard to the elimination or restriction in the use of 40-, 50-, or 60-watt tungsten lamps, and the substitution therefor of 10-, 15-, or 25-watt tungsten lamps. The conditions surrounding the use of these lamps, the locations where installed, the type of fixture and glassware used, and the necessity for adequate illumination either for industrial processes to secure maximum production, or in the home to avoid the glare from naked lamps or the eyestrain that would result from insufficient illumination, make it difficult to recommend the general substitution of lamps of the smaller sizes for the larger size lamps.

"It is possible to obtain the results desired by the Fuel Administration in the form of a saving of fuel in a considerable measure by emphasizing to the consumers of electric light and power and to the public generally the importance of saving electrical energy and hence fuel, the desirability of eliminating every extravagant or wasteful use of light, and by discouraging the use of a larger lamp than is necessary for the immediate purpose for which the lamp is to be used.

"The existing policy of the central stations whereby they recommend to their customers and in various ways encourage the use of standard lamps of medium size, is based upon a broad consideration of all the economies controlling the furnishing to the public of satisfactory lighting service at the lowest total cost. Any temporary departure from that policy toward the encouragement of the use of smaller lamps must, therefore, be recognized as a step taken to meet an existing national emergency and justifiable for this reason.

"The purpose of the program would, in a measure, be defeated and an objectionable condition created if the substitution of types would result, for instance, in the use of two 25-watt lamps where formerly a single 40-, 50-, or 60-watt lamp was used. In considering a more general use of 10- and 15-watt tungsten lamps the increased use of the raw materials required for their manufacture, such as bulbs, brass bases, etc., must be considered, as it would be extremely difficult to obtain them in the increased quantities necessary under present conditions. The difficulty attendant upon making an increased number of low wattage lamps with the necessary losses in manufacture, estimated at from 20 to 25 per cent in excess of the higher wattage type, would introduce a serious dislocation of present manufacturing facilities.

"It would also be pointed out that tungsten lamps of the smaller sizes have filaments which are less robust than those in the larger sizes, their life is consequently shorter and an increased number would be required for renewals, thus overtaxing already overstrained production facilities.

"Attention is also called to the fact that the efficiency of the smaller sizes of tungsten lamps is considerably less than the efficiency of the larger types.

Illumination in War Industries

"Consideration must also be given to the importance of providing adequate illumination in manufacturing and industrial plants engaged on war industries, so as to secure the maximum production now demanded of them. It is the universal experience that a relatively small increase in illumination, affecting the fuel consumed to a very slight extent, results in a comparatively large improvement in both the quality and quantity of the output. It is, therefore, necessary to proceed with caution in advising any restriction of illumination in industrial plants engaged on war industries. On the other hand there are many locations and conditions, particularly in the household, where the larger sizes of lamps are now being used and where smaller lamps would no doubt give adequate illumination, the substitution affording a large reduction in the total consumption of current through which a large aggregate saving of fuel would be effected.

"Where a utility company as a part of its lamp renewal supplies tungsten lamps of both large and small sizes, it is recommended that the difference in the renewal or sale prices between the large and small sizes be based on the actual difference in the cost to the company of the service in each case, and that no attempt be made to influence the use of the larger sizes of lamps by the consumers or the public through the establishment of a price differential that is not justified by the respective service costs.

"By the abandonment of the types as proposed in Article I such carbon lamps as it might still be necessary to use under the special conditions outlined would be of the next smaller sizes.

"It is desirable to secure the complete elimination of the metallized filament "Gem" type of lamps even though the substitution for them of carbon filament lamps in the few exceptional cases where it becomes absolutely necessary to use particularly rugged filaments may result in an apparently increased energy consumption. This increase in a few isolated cases should not defeat the important advantages to be attained by the complete elimination of the "Gem" lamps, an intermediate type between the carbon and tunsgten lamps now become unnecessary.

"In order to secure the most complete elimination possible of the inefficient carbon and "Gem" lamps of all sizes it is recommended that where consumers specifically request lamps of these types from central stations or lamp dealers, their attention be called in each case to the recommendations of the Fuel Administration as outlined in the program, and every effort be made to discourage the use of inefficient lamps by the public.

Working to Improve Tungsten Filament

"Many of these problems would be solved and a complete and almost universal substitute for carbon and "Gem" lamps be provided if a tungsten filament were available very much more robust than the present product. It is understood that manufacturers are now very actively at work on this problem and the outlook for its solution seems very hopeful. The manufacturers should be urged to still greater efforts in order to accomplish this very important result at the earliest possible moment.

"Attention is also called at this time to the importance of the proper rating and labeling of lamps by the manufacturers so that the consumption of energy does not exceed the limits provided for in the government specifications.

"The change in production of lamps from the manufacturing standpoint necessary to meet the program above outlined does not present insuperable difficulties, but will inevitably result in some interference with the business of certain manufacturers producing, wholly or in part, lamps of the types it is proposed to eliminate or the use of which is to be discouraged. It is believed that an agreement may be had with the larger manufacturers whose principal business is the production of tungsten lamps that they may abandon their output of carbon lamps, and transfer of the production of carbon lamps may possibly be arranged under a mutual agreement made through the administrative authorities at Washington between the larger manufacturing companies and the smaller businesses now producing carbon lamps. This phase of the question presents some legal, as well as industrial aspects which can no doubt be satisfactorily adjusted at a conference in Washington between the administrative authorities and the representatives of the parties in interest.

"It is a source of gratification to be able to report that all those present at the several meetings manifested the greatest interest in the proceedings, and displayed a most laudable spirit of co-operation and a readiness to make any reasonable sacrifice of personal interest and commercial advantage to the unselfish and patriotic purpose of aiding the government in every practicable way in meeting the supreme emergency which faces the nation.

"All those present at the meeting pledged themselves to devote their best efforts to making the program effective and in securing for the Fuel Administration the largest possible measure of co-operation to this end from the various organizations which they represented.

"Should this program commend itself to the Fuel Administration, it is suggested that the services of the National Committee on Gas and Electric Service be enlisted in the endeavor to make its provisions effective where desirable, also in co-operation with other similar committees of the industries affected, and also with a view to securing the elimination of inefficient lamps through the checking of the orders for such lamps, and enlightened co-operation on the part of the public in the substitution of the more efficient types."

* * *

On August 29th, the Fuel Administration announced that the lamp manufacturers, at a meeting at Washington on the previous day, had voluntarily agreed to abandon the manufacture of certain types of the inefficient carbon filament lamp in accordance with the program which practically calls for the discontinuance of their manufacture and sale. The announcement adds:

"There are still a few isolated cases where the carbon lamp is required, such as on battleships where excessive vibration or shock calls for a lamp of the sturdy type. But with few exceptions, and these are confined to essential war industries, the program is expected to gradually eliminate the carbon lamp in favor of the more efficient tungsten lamp.

"Central stations, public service corporations, municipal plants, and others who may be using carbon filament lamps are being asked to assist the manufacturers as well as the Fuel Administration in working out this program, inasmuch as sweeping conservation measures are imperative if the war industries and essential public needs are to be supplied.

"The importance of this radical step may be judged from the fact that the program as formally adopted at yesterday's meeting will mean the saving of more than 1,000,000 tons of coal."

Methods for More Efficiently Utilizing Our Fuel Resources

PART XXII. THE FUELS OF CANADA*

By B. F. Haanel

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This installment of our series supplements the last two articles which review the fuel resources of the United States. Canada's fuel problems are intimately related to those of our own country for our northern neighbor imports 55 per cent of her coal and 98.5 per cent of her oil from the United States. Canada's coal resources are second only to our own as far as undeveloped reserves are concerned. The lignite field which contains a large proportion of the coal reserves of the United States extends into Canada where it forms a much greater proportion of the Canadian coal reserves. The high-grade coal fields are much more limited in extent and occur only in the extreme eastern and western provinces. The further development of Canadian fuel resources will be a relief to both countries.—Editor.

If the violent rupture of the peaceful conditions existing some four years ago had not occurred, it is very doubtful whether the subject of fuels would attract any special attention today, unless, perhaps, a discussion of such a subject disclosed new fields for profitable exploitation. Today, however, the attention of the people of this country [Canada] is forcibly centered on this very subject; because we are realizing, perhaps for the first time, our dependence, to so large an extent, on the United States for this essential commodity, and, further, are beginning to understand that our supply of fuels from that country may be cut off at any time.

In the past, and up to the present, we have been depending largely on fuels mined and prepared for the market by labor over which we have absolutely no control. As a consequence, we are at the mercy of foreign strikes and industrial disorganization, and either one or both of these are liable to occur.

A strike of coal miners, or a railroad strike in the United States would affect Canada more seriously in certain respects than the States, since in Canada we should not have the advantage of accumulated reserves which the United States would be certain to have in normal times.

But there is even a more important factor which we must consider, viz., the necessity which may occur for the United States to keep her fuels within her own country. Such a situation may not arise for some time, but the indications are that we may have to meet such an emergency in the near future.

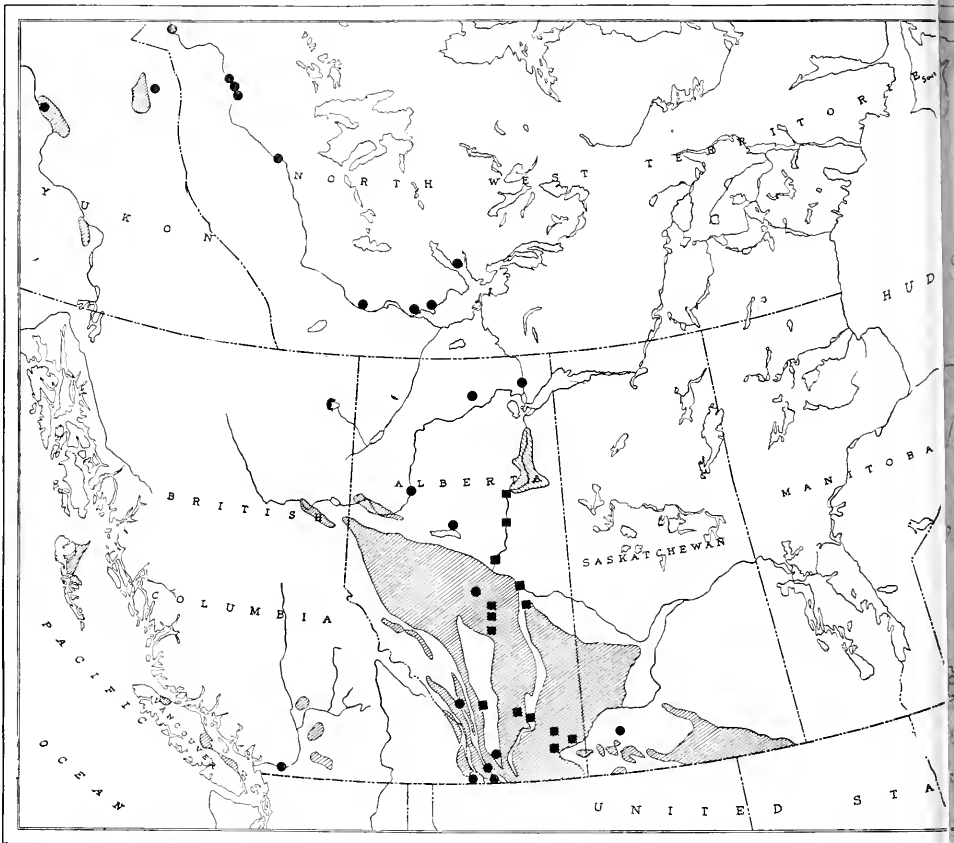
Canada, today, is facing a fuel situation of great gravity; a situation which has not been created by any special conditions in this country, but by those obtaining in the neighboring country. The United States is suffering from a shortage of fuels as a result of the withdrawal of skilled labor from the coal mines to other occupations, and, perhaps more directly, to the abnormal demand on the transportation facilities of that country for the carrying of material directly connected with the conduct of the war.

We are not wholly dependent on the United States for our fuel supply, but we are dependent to the extent of 55 per cent of our total coal requirements and $98\frac{1}{2}$ per cent of our crude and refined oil products. Large and important sections of Canada, moreover, are almost wholly dependent on imported coal for house-heating purposes. This is a matter for grave reflection, since in a country such as ours, where artificial heat must be supplied during eight months of the year for the sole purpose of maintaining life, a continuous and dependable supply of fuel is absolutely essential.

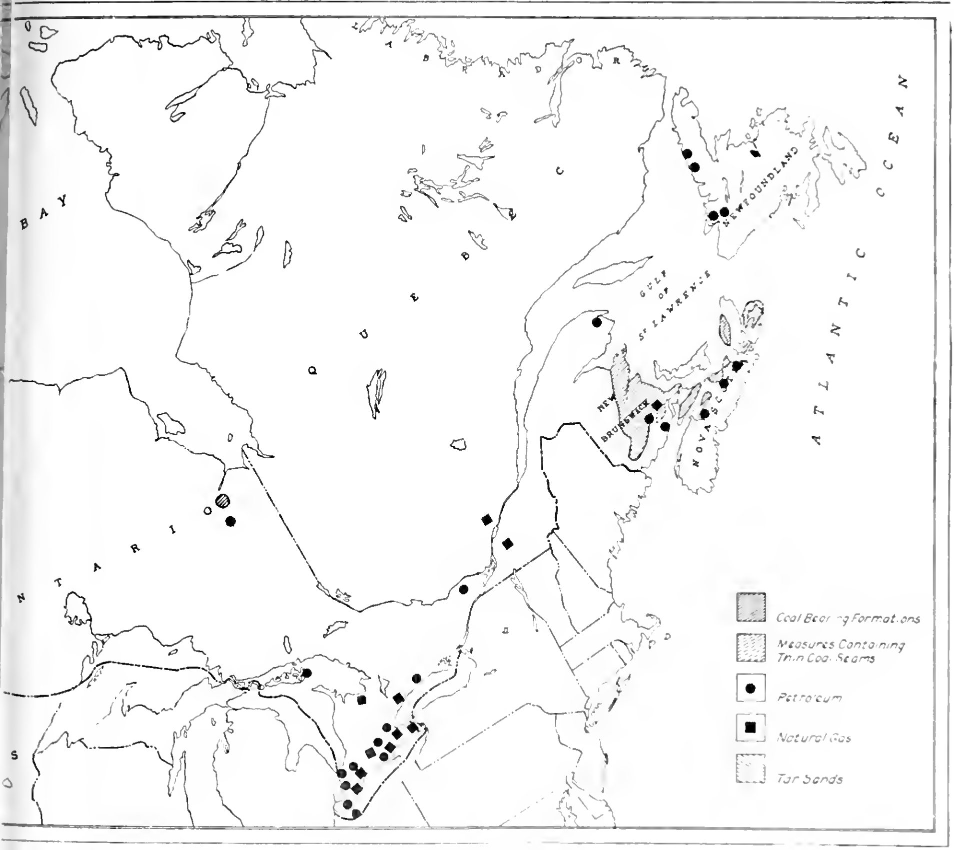
The fuel situation existing in Canada today is due to the ease with which fuels of all kinds, suitable for every requirement, were imported from the United States, and to the apathy displayed towards the exploitation of certain of our own fuel resources by the public at large.

We have not exploited our fuel resources, with the exception of wood, on an extravagant scale, but, on the contrary, we have been culpably neglectful of these vast stores of energy, insofar as we have failed to provide for the future by learning how to use our low-grade fuels, on which at no distant time we shall have to depend. The result of this

* Read before the Annual Meeting of the Canadian Society of Civil Engineers.



Map of Canada showing its deposits of coal, petroleum, natural gas, and tar sands.
reserves are concerned. It will be noted that the high-grade



Canada's coal resources are second only to those of the United States as far as undeveloped coal fields are located in the extreme eastern and western provinces.

neglect to improve our position and render ourselves independent, as far as possible, will be great suffering to the people of Canada, in the event of a stoppage of fuel supplies from the United States, if we do not, at once, take steps to render our own fuel resources available for our own needs.

The present unsatisfactory—indeed alarming—situation can only be improved by a determined and energetic exploitation and utilization of our own vast fuel resources.

I am prepared to show that Canada does possess abundant supplies of fuels, favorably situated, and that these can be exploited in such a manner as to render her much less dependent on, if not entirely independent of, foreign sources for her fuel supply.

Before inquiring into our fuel possibilities, it is necessary to state and analyze our annual fuel requirements.

Canada's Fuel Requirements

The total fuel requirements of Canada during the year 1916 amounted to nearly 30,000,000 tons of coal; 299,426,121 imperial gallons of crude and refined oil products, and firewood valued approximately at $60,000,000.

The railways burned 9,000,000 tons of bituminous coal; 7,000,000 tons were probably required for the purpose of generating power, and a large quantity was used for making retort or town gas, heating large buildings, and the manufacture of coke. Over 4,000,000 tons of anthracite were burned in domestic and other heating plants, and, to some extent, were used for industrial purposes. In normal times, practically the entire imports of anthracite coal are used for heating purposes.

Compared with her annual requirements, Canada's production of fuels for the same period amounted to 14,483,395 tons of bituminous coal, of which 2,135,359 tons were exported; 6,934,288 imperial gallons of crude oil; and wood fuel to the value of $60,000,000. To meet our own needs, therefore, it was necessary to import 17,580,603 tons of coal, and 292,426,121 imperial gallons of crude and refined oil products.

Of this quantity of oil, approximately 50,000,000 gallons were used on the railroads; 30,000,000 gallons for steamships, and the remainder, 210,000,000 gallons, was used for lighting and heating, in the form of kerosene and, to a large extent, in the form of gasolene for power purposes.

This is a general statement of the extent of our dependency on the United States for these essential commodities.

An analysis of our fuel resources, their location and extent, will reveal the reason for the necessity of these excessive imports.

Fuel Resources of Canada

The fuel resources of Canada exist in the vast coal fields of the extreme eastern and western portions of Canada; the lignite fields of the western provinces; the natural gas fields of Western Canada and the province of Ontario; the petroleum fields of Ontario; the oil shales of New Brunswick, Nova Scotia, and elsewhere; the standing forests, and, last, but not by any means the least important, the great areas of peat bogs. This is a truly formidable array of resources. Now, let us inquire into their extent, quality, and location, since these are the most important factors concerning their exploitation.

The following is an estimate of the actual coal reserves of Canada, based on actual thickness and known extent. The location and approximate classification of the coals are also designated:

	Million Tons	
Nova Scotia	2,137	Bituminous coal
	50	Cannel coal
Saskatchewan	2,412	Lignite
Alberta	382,500	Lignite or sub-bituminous
	1,197	Low-carbon bituminous coal
	2,026	Anthracite and bituminous
	669	Semi-anthracite
British Columbia	23,653	Semi-anthracite and bituminous
	118	Low-carbon bituminous coal
	60	Lignite

In addition to these admittedly great reserves, we have in this country 37,000 square miles covered with peat bogs. The total estimated tonnage of fuel represented in this area is 28,000 million tons of 25 per cent moisture peat fuel, equivalent, on the basis of actual heating value, to about 16,000 million tons of good coal. Of this total area, however, only a portion is favorably situated with respect to economic development. 12,000 square miles of peat bogs are distributed throughout the central provinces: Manitoba, Ontario, Quebec, and New Brunswick, and the estimated tonnage of peat in this area is 16,000 million tons, equivalent, on the basis of actual heating value, to 9,000 million tons of coal.

No estimate can be made of the forests of Canada which are available for firewood; and natural gas has a special value only in those districts which can be economically served with this fuel. Natural gas is of great value when it can be obtained in large quantities in well-populated and industrial communities, but it possesses the disadvantage of being an uncertain source of heat.

Of petroleum, all that I shall say, at the present time, is that Canada is manifestly not a petroleum-producing country.

The principal fuel resources, then, which we have to consider are the bituminous and anthracite coals, the lignites, and peat. Oil shales and other sources of oils will be considered later.

The statement of the distribution of our fuel resources discloses the fact that the true coals are situated in the extreme east and west, and the western part of Alberta; the lignite coals are situated in the provinces of Alberta and Saskatchewan, but lying between the limits of these deposits is a great stretch of territory devoid of coal of economic value. The 12,000 square miles of peat bogs are situated in this area.

The country naturally lends itself to a division into four parts or districts, and each district has an abundance of fuel peculiar to its own area. The first district embraces that portion of Western Canada which can be economically supplied with bituminous and anthracite coals; the second district, that area which can be supplied with lignite; the fourth area, that portion of Canada which can enjoy the full advantages of Nova Scotia coal. The third district cannot be economically supplied with any of the above coals. This area must either render itself independent of foreign fuel sources by developing and utilizing its excellent peat bogs, or remain, to a large extent, dependent on the United States. A large portion of the province of Ontario is principally affected in this manner.

To supply certain of these areas with fuel of the desired quantity and of a quality suitable for various purposes, constitutes a problem which must be satisfactorily solved before we can improve our fuel situation.

The bituminous coals of Canada are similar to those of the United States, and include large quantities of excellent coking coal. Their utilization for general industrial purposes presents no difficulties whatever, but for domestic purposes bituminous coal, in its raw state, is far inferior to anthracite, which is the fuel almost entirely used for these purposes in Canada. A most excellent fuel, practically the equal of anthracite, can, however, be produced from bituminous coal by a special process consisting of carbonization at low temperature and briquetting. This process is in actual operation today turning out briquettes entirely satisfactory for domestic purposes.

With lignite and peat, however, the situation is totally different. In their raw state, peat and a large portion of the lignite are not suitable for use. These fuels must be submitted to some preliminary treatment before they can be utilized for general fuel purposes.

When the peat deposits of the central provinces, and the lignites of Saskatchewan and Alberta are rendered into forms convenient and suitable for domestic and industrial purposes, the fuel situation, so far as Canada is concerned, will have been greatly improved.

Before treating these two fuels in detail, it is necessary to draw attention to the fact that the transcontinental railways traversing the western provinces are prohibited by an order of the Railway Commission from burning lignite in the locomotives during the summer months. These railways, on their west-bound trips, are consequently compelled to burn imported coal to that point in the western coal fields where they can again replenish their tenders with native bituminous coal. The same thing takes place on that portion of the eastbound trip traversing the province of Ontario.

Apart from this order issued by the Railway Commission, the railways would much prefer to haul and burn imported coal, inasmuch as lignites at least certain of them are not suitable for locomotive use.

The railways of Ontario also are entirely dependent on imported coal.

Preparation of Lignite and Peat for Economic Utilization

The utilization of certain of the lignites for some purposes is possible without any subsequent treatment. With others, however, notably those of Saskatchewan, the lignites as mined are not suitable for use. This is due to the physical and chemical properties peculiar to this type of fuel.

Lignites usually contain large quantities of moisture, ranging from 16 to 35 per cent of the weight of the fuel, and the evaporation of this moisture, whether by natural or artificial agencies, results in the disintegration of the fuel. This disintegration, however, does not discontinue when the evaporation of the moisture is complete, but appears to go on indefinitely.

One more peculiarity must be mentioned, viz., the dangerous sparks emitted from the stacks of locomotives when lignite is burned. These sparks, when they emerge from the stack, burn with a small flame and this flame is not extinguished by its passage through the air, as is the case with bituminous coal or anthracite coal sparks, but continues to burn after lighting on the ground. On account of this dangerous property, lignites cannot be safely burned in locomotives.

Lignite, unlike the true coals—bituminous and anthracite—lacks definite structure. (This term is employed in its physical sense.) To this may be attributed the reason for the difficulty with which lignites submit to mechanical treatment.

The characteristics of lignites must be altered before they can be converted into a satisfactory fuel. Experiments on a commercial scale have demonstrated beyond doubt the fact that our lignites cannot be briquetted in the raw state with or without the addition of a binder. Briquettes made in this manner appear, on casual examination, to be entirely satisfactory, but when submitted to a water test, or when burned, they will invariably disintegrate.

The characteristics of a lignite are changed by carbonizing it at low temperature. During this process the moisture and volatile matter are completely distilled off, and there remains in the retort a residue composed of practically pure carbon. This residue is then mixed with a suitable binder, and briquetted. In order to render this briquette waterproof, a second heat treatment, or baking, is necessary. A fuel entirely satisfactory in every way, waterproof, capable of resisting disintegration when exposed to the weather, standing rough handling without breaking, not emitting flaming sparks, and capable of maintaining its physical structure or shape under the action of heat until completely consumed, has been produced by such a process. In order to demonstrate that this process will solve the problem in connection with our western lignites, it is advisable to erect a commercial plant capable of producing one or two hundred tons of lignite briquettes per day. Such a plant would have to be equipped in such a manner as to allow of a certain amount of experimental work being performed, e.g., in connection with binders.

I am of the opinion that it would require only a comparatively small amount of money—i.e., compared with the immense value which the solution of this vitally important problem would be to the country—to successfully demonstrate that the lignites of the west could, by means of such a process, be converted into a fuel entirely satisfactory for domestic and industrial purposes.

The establishment of briquetting plants at strategic points throughout the lignite provinces of the west would very greatly help in reducing our dependency for fuels on other sources. While a domestic fuel is, of course, of first importance, lignite briquetting industries would prove also of great value to the railways traversing the lignite belts. It would even be within the realm of possibility to economically supply at least a portion of the province of Ontario with this class of fuel.

The only remaining low-grade fuel to consider is peat.

Peat Fuel

The exploitation of our peat resources for the manufacture of a fuel does not involve any research work or experimentation. An economic process for the manufacture of raw peat into an excellent fuel suitable for domestic and, to some extent, industrial purposes, is in use today, and has been employed for many years in the peat-using countries of Europe. There is a flourishing and extensive peat industry in several of the European countries, but in Canada, a country possessed of magnificent peat resources and dependent to so large an extent on foreign supplies of coal, no peat industry exists. This deplorable state of affairs is due to misdirected energy in connection with the many attempts made to manufacture a fuel from peat, and to a general lack of interest towards anything connected with "peat" by the influential men of Canada.

Whether or not a particular natural substance shall be exploited has usually been decided from a "profit" point of view. Peat, not holding out great prospects for fabulous profits, failed to attract the attention of the large capitalists and industrial men. The creation of a peat industry was, therefore, left to the mercy of a few earnest and honest men with insufficient capital to prosecute an undertaking of this kind to a successful issue, and to a few fakirs and otherwise unscrupulous promoters, whose sole aim and purpose was "to get away with the money" before being discovered. Without going into detail, let it suffice to say that several attempts have been made and as many failures with loss of capital involved have been recorded; but the larger portion of the capital lost could have been saved and a flourishing peat industry long ago established if the promoters had been advised by accredited engineers who understood their business. Instead, however, of profiting by the experience of European investigators—gained at great expense—money was expended in developing and trying out ideas which had long before been discarded as impracticable, and, in many cases, impossible, by the investigators and engineers of the peat-using countries of Europe. Not until the results of the investigations conducted by the Mines Branch of the Department of Mines concerning the economic methods employed for the manufacture of peat fuel in European countries were placed at the disposal of the public, were men with impractical ideas dissuaded from interesting people in their schemes. Men of this description are still found going from place to place in a vain endeavor to interest capital, but they are rapidly disappearing.

Not until the utilization of a natural substance is forced by absolute necessity, will the most sincere and earnest efforts be put forth to successfully and economically convert it into a usable product. It appears that the time is at hand when necessity will decide that we Canadians utilize our peat resources, and in the most efficient manner.

Peat in its natural state is generally associated with about nine times its weight of water. It is, therefore, evident that 1800 pounds of water must be removed in order to recover 200 pounds of solid matter. Moreover, this solid matter not only represents the combustible substance, but also the ash and mineral matter which is associated with the peat.

The separation of this large quantity of water, and the handling of so large a quantity of raw peat substance, in order to obtain a comparatively small quantity of combustible matter, represent the difficulties with which we are confronted when an attempt is made to manufacture peat into a fuel, on a commercial basis, and in a thoroughly economic manner.

The only economic process in existence today is that which employs the forces of Nature—the sun and the wind for the removal of the moisture. The process employing these forces is called the "wet process," and the product obtained is termed "machine peat." This is the process which the Mines Branch, Department of Mines, demonstrated at the government peat plant at Alfred, Ontario.

We not only have the process for manufacturing peat fuel, but also sufficient detailed information concerning peat bogs of immediate importance, to make a good start in the formation of a peat industry.

During the period covering the past ten years, the Mines Branch has completely investigated and mapped 58 Canadian bogs, all of which are situated conveniently with respect to inhabited and industrial communities, and also well situated with respect to railway and other transportation facilities. The investigations are conducted with a view to determining the principal and controlling characteristics of a bog, viz., its area, depth, quality at different depths, quantity in tons, and, in general, its suitability for any particular purpose. The area examined in detail comprises 170,000 acres, and represents a quantity of standard peat fuel, i.e., fuel containing 25 per cent moisture, estimated at 120,000,000 tons. Seven bogs conveniently situated with respect to Toronto could supply that city with 26,500,000 tons of fuel, and seven bogs in easy reach of Montreal could supply 23,500,000 tons of fuel. Excellent bogs are, likewise, conveniently situated with respect to thickly inhabited communities in Nova Scotia, New Brunswick, and other parts of Canada. This completes our inventory of the solid fuels. In regard to oil, we are not so favorably situated.

Sources of Oil

The oil fields of Ontario, the oil shales of New Brunswick, Nova Scotia, and elsewhere, and the bituminous coals and lignites constitute the only economic sources of oil known to exist at the present time. Energetic and intelligent prospecting directed by able petroleum geologists may disclose new oil fields of economic importance. This, however, must be accomplished before the above statement of our oil resources can be modified.

The productivity of the oil fields of Ontario is decreasing at so rapid a rate that it will be comparatively only a short time before they will cease to be a source of oil.

The oil shales of New Brunswick and Nova Scotia are, on the other hand, a most valuable source of oil. They are of large extent and rich in oil. The average oil content of a large number of samples representing various portion of the New Brunswick shale deposits is from 35 to 40 imperial gallons per ton, and if these samples are representative of the entire deposits, the total quantity of oil contained in these shales is very large.

Our bituminous coals and lignites also may become important sources of oil. The yields of benzol and tar from one ton of bituminous coal when cooked in a by-product recovery oven are respectively 1½ and 5 gallons. The maximum yield of oil which might be expected when lignites are distilled solely for this purpose is probably not more than 3 per cent of the weight of the fuel distilled. This figure may be subject to change; but the results of the work so far completed by the Mines Branch in connection with an investigation concerning the value of lignites as a source of oil do not indicate that a higher yield can be expected.

The total quantity of coal coked in Canada during 1915 was 1,856,393 tons, and if this quantity were coked in by-product coke ovens the yields of benzol and tar would be 2,800,000 and 9,000,000 gallons respectively. This yield of benzol could be further increased by distilling the tar recovered. The maximum quantity of benzol which could be recovered from the above quantity of coal is about 3,712,786 gallons.

The yield of light and heavy oils from 1 ton of bituminous coal is considerably increased when this coal is carbonized at low temperature.

Our oil requirements, as stated before, were in 1916 nearly 300,000,000 imperial gallons, while our domestic production was less than 7,000,000 gallons. A small quantity of benzol also was recovered in the by-product coke ovens operated during that year. In order, therefore, to produce sufficient oil to equal our imports of this commodity, we should have to distill an enormous quantity of coal and lignite, or oil shales, or both. The production of 300,000,000 gallons of oil from lignite would necessitate the distillation of about 30,000,000 tons of this fuel. This is manifestly impracticable.

As far as the oil shales are concerned, their distillation on a very large scale is not only entirely practicable, but very desirable. Large plants for the distillation of oil shale are in continuous operation in Scotland, and such plants were in operation in France prior to the war. Our shales are in no sense inferior to those of Scotland and could be exploited as easily and as profitably. No sound reason, therefore, exists for allowing this valuable source of oil to lie undeveloped.

Our domestic production of oil cannot be increased without great effort and the expenditure of considerable money, but provision must be made, and made immediately, to provide against the time, not far distant, when the United States will be compelled to cease exporting her crude and refined oil products.

This will be forcibly brought into evidence by the following statement regarding the present status and future outlook of the oil industry in the United States. The production of oil, from 1859 to the year 1915, was 3,616,561,244 barrels, of 43 gallons to the barrel, and the possible future production is estimated at 7,629,000,000 barrels. This estimate was prepared for Senate Document 310, and was made by thirty prominent petroleum geologists of the United States Geological Survey. The United States, up to the year 1915, had exhausted 32 per cent of her possible petroleum resources. If the present annual production is maintained, but not increased, her total crude oil supplies will be exhausted in less than 30 years. But if the present rate of increase of production is maintained, total exhaustion will occur in a much shorter time.

It is apparent, then, that we shall not be allowed to enjoy the advantages of the oil resources of the United States for a great while longer.

We can scarcely hope, for some time to come, to produce oil on a scale comparable with our demands—but we can appreciably reduce the quantity which must be imported, and when oil can no longer be imported we shall simply have to reduce our requirements or else find a substitute.

Our total oil production from all sources might probably be increased to 120,000,000 gallons; by erecting oil shale distillation plants in New Brunswick with a combined capacity of 100,000,000 gallons and by increasing the quantity of coal coked in by-product ovens or by carbonizing large quantities of bituminous coal at low temperature and briquetting the carbonized residue.

The low temperature carbonization and briquetting of Nova Scotia coal either in Nova Scotia or at some center of distribution favorably situated with respect to water transportation—as Montreal for example—would not only appreciably increase our production of oil, but would also be the means of supplying, for domestic purposes, a coal equal in many respects to anthracite.

The fuel situation of some parts, at least, of Ontario might in this manner be much imimproved.

If this idea were carried out, our oil production would be:

	Gallons
From oil shales	100,000,000
From coke ovens and low temperature carbonization	14,000,000
From Ontario petroleum fields	6,000,000
	120,000,000

This completes the survey of our fuel resources and our fuel situation as it exists today. The fuel situation of the future will depend on the efforts we make to render our own fuel supplies available for utilization by the people.

Economic Utilization of Our Fuels

I desire now to deal with the methods to be employed for the utilization of fuels in general, in order to convert the maximum of their heat energy into usable forms of energy, and to recover the maximum of the valuable chemical compounds which can be obtained from the solid fuels.

All of the solid fuels contain the element nitrogen, some to a very large extent, and this is the basic element of a most important chemical compound—ammonium sulphate. In normal times this substance is used very extensively for agricultural purposes, in order to restore to the exhausted wheat fields and other agricultural lands the essential nitrogen which has been removed, almost to exhaustion in certain instances, by the repeated raising of the same crops.

The necessity for employing such a fertilizer on our Western wheat fields may not be apparent to everyone, because of the large increase in our wheat production reported from year to year. This is directly due to the large crops realized from the new virgin fields which are put under cultivation each year. The average yield per acre of the older wheat fields, however, is rapidly decreasing, and if their production is to be maintained or increased an artificial fertilizer will have to be employed.

This fertilizer is, however, in great demand in other countries, and its recovery in Canada and sale to other countries would, in many cases, prove to be a profitable venture.

The solid fuels are burned on a large and continually increasing scale for the production of power, town or retort gas, for the manufacture of metallurgical coke, and for general heating purposes.

The employment of the by-product recovery coke oven for the manufacture of metallurgical coke is taking place on a large and rapidly increasing scale in the United States, and Canada is now employing such ovens to a considerable extent. The manufacture of coke in by-product ovens is attended with the recovery of ammonia and the oils previously referred to. The entire quantity of coal used for coke and gas making should be utilized according to this method.

Power, other than hydroelectric, can be produced from the solid fuels in two principal ways: through the media of, first, the steam plant; second, the gas producer plant.*

When the energy of coal is converted into useful work by the first method, all valuable by-products are forever lost. When the second method is employed, and the producer is of the by-product recovery type, it is possible to realize a maximum recovery of the nitrogen content of the fuel.

The producer gas by-product recovery plant is eminently suitable for the production of a power and industrial gas, and the field of its application might be extended to include the supply of gas for certain domestic purposes, e.g., general heating. Such a gas possesses the advantage of low cost, inasmuch as the plant can be situated at or near the source of fuel. Moreover, the cost of operating the plant can be appreciably reduced through the sale of the by-products, and this results in a further reduction of the cost of the gas if the production of gas is the main purpose.

We, however, possess sources of fuels especially high in nitrogen, viz., the peat bogs. The average nitrogen content of all the peat bogs so far examined is high—but there are a few notable peat bogs of large extent, containing fuel of excellent quality, in which the nitrogen content is very high. The fuel of such bogs should unquestionably be utilized in by-product recovery producer gas plants, for the production of power or a power, industrial, and domestic gas. The bogs referred to and described in detail in Mines Branch Report 299, are favorably situated with regard to populated communities and industrial centers.

Some of our fuels are especially valuable for purposes for which no other fuel can be substituted. This is especially the case in the

* Part II of this series, GENERAL ELECTRIC REVIEW, September 1917, describes a power plant at the Fushun Colliery of South Manchuria Railway wherein the gas from by-product producers is burned under boilers which, in turn, supply steam to turbines. This is now considered to be the most economical method for generating power from gas.—EDITOR.

coking variety of bituminous coals, and these fuels, at the present time, are being used indiscriminately for all purposes, notwithstanding the fact that the coking coals are invaluable for many metallurgical purposes and cannot be replaced, by any means known today, with non-coking coal. A coking coal should, therefore, never be used for any purpose for which a non-coking coal will be entirely suitable.

The quantity of coke produced in Canada today is small, and the necessity for conserving this class of coal may not be apparent. The great demand, however, for metallurgical coke in the United States and the probable depletion in the not far distant future of the supplies of this fuel in that country will, in time, make our deposits of coking coal of special value. When that time arrives we shall have an excellent commodity for purposes of barter, if we now take steps to conserve our supplies.

The problems associated with the distribution of fuel to the various parts of Canada are somewhat complicated, owing to the distribution of its population. In order to supply heat and power in the most economical manner and at the lowest cost to a population so widely scattered, the most rigid economy must be installed. The added cost to a fuel consequent on large rail haulage and local distribution can be very materially reduced by centralizing heating and power plants.

The populated sections of the country should be carefully studied with a view to its logical division into sections, each of which could be economically supplied with heat and power by one central heating or power plant. If this were carefully followed out, very marked economy would result in both the use of the fuel and its cost to consumer. The difficulties entailed in the distribution of the required fuel for such communities would, at the same time, be very largely overcome.

Many of our industrial plants have been located without any regard to the source of power or fuel on which they depend. Such industries, wherever it is possible to do so, should be moved to a locality which can be economically served with hydroelectric energy or electric energy generated in a large central plant, and industrial sites in general should be set aside for the location of all future industries.

It is evident that our fuels cannot be used indiscriminately and without the exercise of some degree of intelligence. We must not only meet all our own fuel requirements and place the people of this country in such position that they will not need to worry about a possible coal famine, but we must, at the same time, utilize our fuels in the most advantageous and economic manner. Great as our fuel resources are, we must practice conservation. Only by doing this do nations become strong and powerful.

The fuel situation of Canada, as I view it, is not a gloomy or discouraging one, for we are endowed with fuel deposits on a magnificent scale. All that is necessary now is that their proper exploitation and economic use be assured.

An Ideal Twenty-four-hour Load Now Awaiting Central Station Power

By S. G. Gassaway
San Francisco Office, General Electric Company
and W. G. Taylor
Power and Mining Engineering Department, General Electric Company

The fuel oil shortage now developing, which is analyzed by the authors in an interesting manner, brings to the front the fact that in the oil fields themselves an exceptionally large saving in oil can be obtained by electrification. Not only is the opportunity for the extension of electric power there a large one, but the load itself closely approaches the ideal sought by central stations, as the illustrations attest. The article will for this reason be of particular interest to central station men.—Editor.

Today, the consumption of crude oil and its products is running far in excess of the production. Last year, the United States consumed three hundred and ninety million barrels of petroleum for domestic and export purposes, but produced only three hundred and thirty-five million barrels. The deficiency of fifty-five million barrels was met by drawing twenty million barrels from stock and importing thirty-five million barrels from Mexico.

It is stated that this year the Allies will need four hundred and thirty million barrels of crude oil, the greater part of which will have to come from the United States. It is doubtful whether the United States' production for this year will exceed by fifteen million barrels that of last year. The Mexican fields can supply one hundred and thirty million barrels, but that supply is largely dependent upon the internal conditions there.

The United States Fuel Administration has succeeded in curtailing the use of fuel oil in the non-essential industries, thus providing a partial supply for the increased demand of those which are essential. A number of the industries have adopted the practice of burning powdered coal and have thus effected a very substantial saving in fuel oil, but even with that saving the demand for oil is still far in excess of the supply.

Considerable economy has already been effected by the Federal Administration in the operation of the railroads which last year used forty-five million seven hundred thousand barrels of oil for fuel. The Oregon Short Line and industries in the Northwest have saved approximately one million barrels of oil a year by using coal, and a further saving has been effected by the abolition of several trains and by the rearrangement of freight and passenger schedules to eliminate duplication. Notwithstanding these efforts, oil production has not yet caught up with consumption; and the storage of petroleum in the United States is still being drawn upon at quite a high rate. It is questionable as to whether much additional saving can be effected by the use of coal, for the production of coal is already far behind, and it would seem as though further effort along this line would merely be a matter of "robbing Peter to pay Paul."

Assuming that coal could be produced in sufficient quantity for railroad use, thus effecting a very large saving in fuel oil, it is doubtful whether the substitution would be feasible because of the resultant congestion caused by the cars required to handle the coal. The Southern Pacific Company, for example, could use eleven thousand tons of coal a day, but to handle this amount would require between four and five thousand coal cars which would be a very serious matter over its already freight-congested system. Besides, the railroad has not this number of coal cars available.

Depletion of Oil in Storage

In June, 1915, California had the largest amount of oil ever accumulated in storage, amounting to sixty-three million barrels. By December 31, 1917, this had been reduced to thirty-two million, four hundred thousand barrels. Similarly, the United States as a whole had its maximum of two hundred and thirteen million barrels of oil in storage in September 1915, and of this only about one hundred and forty-two million barrels remained on July 31, 1918.

The ratio between production and consumption of petroleum varies from month to month and from day to day. For instance, in California the consumption in one month averaged forty-three thousand barrels per day greater than the production; but for the month of May, 1918, the average daily

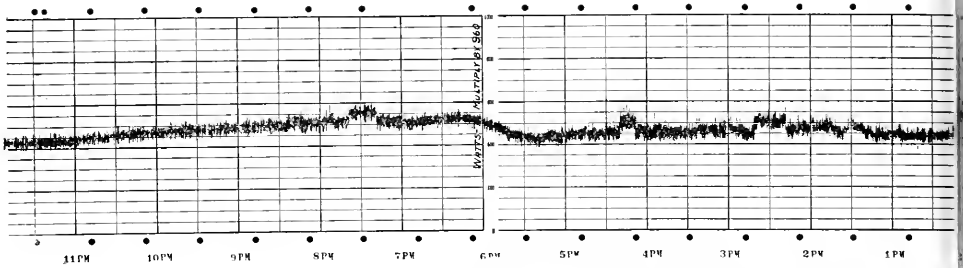


Fig. 1. Twenty-four-hour Load Curve of Sub-station for Midland Counties Public

production exceeded the consumption by one hundred barrels. This latter figure was probably due, however, to a shortage of bottoms and other transportation facilities, and also to the "bringing in" of some new wells which, for the time being, give a large production. The annual figures for California, being typical of the entire United States, are as follows:

1915. The demand exceeded the supply by 1,379,223 barrels for the year, or an average of 3,779 barrels daily.

1916. The demand exceeded the supply by 13,110,861 barrels for the year, or an average of 35,822 barrels daily.

1917. The demand exceeded the supply by 11,585,725 barrels for the year, or an average of 31,742 barrels daily.

1918. For the first five months of 1918, the demand exceeded the supply by 1,667,616 barrels, or an average of 11,056 barrels daily.

These figures are for California only, and while the withdrawal from California stocks has slackened somewhat, partly because of lack of transportation facilities, the situation for the entire United States has grown worse. For the year ending July 21, 1918, the drain on United States stocks was 23,134,948 barrels, or a daily average of 63,383 barrels.

It is obvious that there will have to be further curtailment of the use of fuel oil in the United States, otherwise our industries—in fact those of the entire world—will suffer seriously. This country produces sixty-five per cent of the world's petroleum, and more than half of the remaining production is from Russia and other countries now under

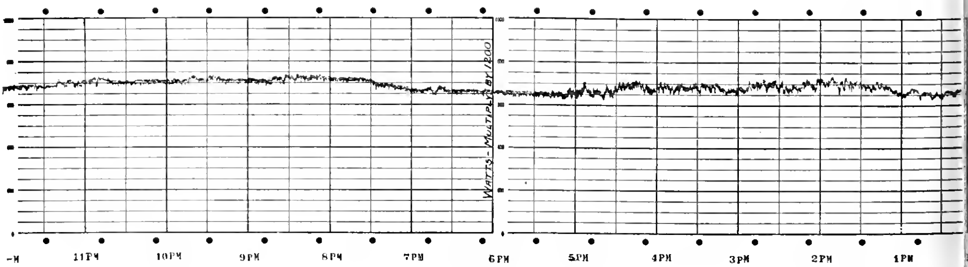
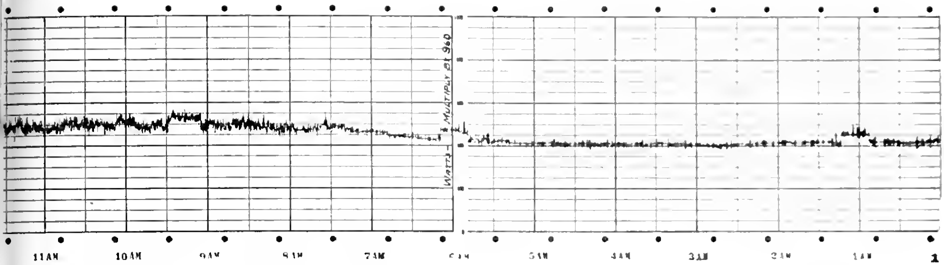


Fig. 2. Twenty-four-hour Load Curve of Sub-station of San Joaquin Light and



Service Corporation serving a portion of the Coalinga Oil Field in California

the control of Germans. Petroleum is most essential for the effective carrying on of this war, and after the war it will be fully as essential for the rebuilding of the world. It is necessary, therefore, that every possible saving be made which can be effected in the use of petroleum.

Two Large Sources of Saving

There are two chief sources of saving possible in the use of fuel oil in the United States:

(1) On the western railroads.

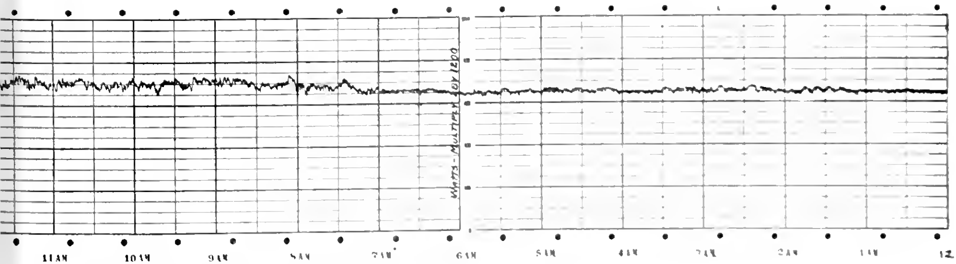
(2) In pumping in the oil fields.

Electric power is admirably adapted and successfully used for both of these purposes.

A few facts concerning the railroads will be mentioned only in passing. The Pacific Divisions of the Southern Pacific and Santa Fe Railway Companies used twenty-five million barrels of oil in 1917 in their locomotives. At a price of $1.60 a barrel, at which it is now impossible to obtain fuel oil delivered on contract at railroad loading stations, this oil had a value of forty million dollars. This sum would go a long way toward electrifying these two systems.

Fuel Oil Consumption in the Oil Fields

In the oil fields, a large saving in fuel can be quickly realized. In California, alone, the oil operators are annually using eight million three hundred thousand barrels of oil for fuel in refineries and field operations; and of this, seven million barrels are burned under boilers in the field for generating steam. In the oil fields of the United States, over twenty-two million barrels of oil are thus burned annually under boilers supplying steam pumps. Should all the California operators use electricity in place of the present steam power, the seven



Power Corporation serving a portion of the Midway Oil Field at Taft, California million barrels of fuel oil which they would save would amount to an actual increase of that amount in their annual net production, and any fuel oil used for producing the electric power would be much more efficiently utilized. However, electric power could in most cases be developed from water power, coal, or natural gas.

It is estimated that the California operators expended twenty million dollars in 1917 in new wells, and at least sixty million dollars for this purpose during the five-year period ended in 1917, yet all of the expenditure in 1917 failed to increase their yearly production and barely maintained it at the same figure as for the previous year. Of this amount, twelve million dollars would suffice to equip the California wells not yet electrified with electric power,* including the expenditures necessary by the power companies to handle this load, and not only would this maintain and even increase production but the production formerly used for fuel and thus saved would be a permanent supply, as it would not decline from year to year as does the production from new wells.

Economy of Electric Drive

The total value of the twenty-two million barrels of oil which might thus be saved in this country is well in excess of forty-five million dollars. It is reasonable to believe that if the power company could effect an annual net saving to the oil operator of fifteen million dollars of this amount, he would in turn be quite willing to pay the remaining thirty million dollars a year for electric power instead of burning oil for fuel.

Can this saving be effected? For answer let us turn to a few typical cases wherein electric power has been installed, taking into consideration only those items affected by the change to electric drive; such as, fuel, water, labor, maintenance, repairs, and electric power.

The British Consolidated Oil Corporation, Limited (now the Indian and Colonial Development Company) made a saving in excess of twenty-two per cent on twelve wells in the California Midway field.

In the Coalinga field in California, one oil company installed motors on a group of wells and discarded twelve boilers, thereby making a saving of sixty-three per cent in the operating expenses.

*Some two thousand California wells are now operated by electric power.

The Salvia Oil Company (formerly the Wabash Oil Company) in the Coalinga field could not produce enough oil, above that used for fuel, to pay operating expenses, and was thereby forced to suspend operations until two enterprising operators recognizing the possibilities of electric drive took over the property, installed electric drive on all the wells, and are now actually paying dividends.

Another company saved thirty-six per cent on eight wells; another twenty-four per cent on twelve wells; and another forty per cent on one hundred and seven wells.

The foregoing figures were obtained previous to this year. Because of the immense increase in the last few months in cost of labor, the saving effected by electric motors is consequently now much greater.

Oil Production Lost Due to Interruptions

It is obvious to anyone that oil field production can reach a maximum only by continuous operation of the wells. Interruptions or shut-downs seriously curtail the amount of oil produced. With electric motors it has been found possible to keep the wells producing more nearly continuously than with steam or gas engines. It is true that the gas engine uses no oil as fuel and, for this reason, it might seem paradoxical that the electric motor can operate more cheaply, but the fact that it does has been proved by the many cases wherein electric motors have been substituted for gas engines. It is difficult to keep the gas engine operating continuously because of the wear and tear on the moving parts, and of other troubles characteristic of this form of prime mover. The result of replacing gas engines by electric motors has increased production from five to fifteen per cent because of the fewer shut-downs. Furthermore, the repair cost when operating gas engines is notoriously high, and this often is greater than the charge for electric energy.

Electric Equipments and Future Business

Motor equipments have been standardized for all power purposes in oil field operations, special features being used only for the particular service intended. Scores of oil companies are now operating several thousand wells by electric power.

The possibilities of the future are indicated by the fact that California today has eighty-three hundred producing oil wells; Texas and Oklahoma have seventy thousand shallow wells and twenty-five thousand deep wells;

and Kansas has twenty-five hundred deep wells and, in addition, several hundred shallow ones. California is drilling wells, mostly deep ones, at the rate of seven hundred a year. In 1917, Texas and Oklahoma drilled six thousand wells which produced oil, and today are operating approximately fifteen hundred sets of drilling tools which it is estimated will drill four thousand producing oil wells per year.

Most of these deep wells can be pumped with an individual oil-well motor of the two-speed varying-speed type, and the shallow wells as well as some of the old deep wells can be pumped in groups on jack-powers driven by standard induction motors. Thus Texas and Oklahoma alone could use ten to twelve thousand two-speed motors and perhaps thirty-five hundred standard induction motors.

Nature of the Oil Field Load

As the title of this article indicates, an oil field load is an ideal one. It is practically constant twenty-four hours a day, every day in the year. It is true that in individual installations there are relatively heavy peaks in the energy demand, but these peaks are not felt at the generating station or substation because of the diversity factor of a large number of installations.

Figs. 1 and 2 are photographs of actual curve-drawing wattmeter records taken from the substations of power companies serving typical oil fields. It is to be noted that these records, for the most part, show a practically constant load not materially affected by the peaks on the individual installations. In some cases the load is greater at night than during the day, this being explained by thelarge lighting load around the oil fields.

If those central stations which have oil fields within their territory and which are not already alive to the unusually desirable features of this load will give this matter the consideration it merits, they will undoubtedly be acting not only to their own advantage but also in the interests of conservation of our national fuel oil supply.

Time Limit Induction Overload Relay

By F. E. Jaquay

Switchboard Sales Department, General Electric Company

The relay described in this article is built on the principle of the well-known induction type meters. The contacts are closed by a rotating element supported by jewel bearing and pivot. The relay is provided with a temperature compensating device which causes it to function correctly with large variations of temperature, and provision is made for a wide range of adjustments for time delay and current values at which the relay will trip.—Editor.

This article is a discussion of various improvements which have been incorporated in the time limit induction overload relay described in the October 1916 issue of the Review.

This device, Fig. 1, is of instrument construction, and has a jewel bearing and pivot of the same special quality as is used in G-E induction meters. With the application of the heaviest currents due to abnormal circuit conditions, the relay performs its circuit-closing operation as quietly and with the same precision as an induction meter under normal load. It is simple and substantial in construction and requires the minimum of attention. Time and current settings are made conveniently, the operating characteristics are permanent, and the accuracy of time delay is unusually high. This combination of qualities makes this relay particularly adapted to service which requires accurate time selective action.

The relay has a normal rating of 5 amperes and is suitable for operation from current transformers. The details of construction are, however, somewhat different for 25 and 60 cycles.

The relay has four back-connected studs, two for the rotating element and two for connection to the tripping contacts. These studs also assist in supporting the relay on the panel. A glass cover, through which the moving parts are plainly visible, is secured to the relay against a felt gasket which excludes all dust. The cover can be readily sealed if desired to insure against the settings being changed except by authorized persons.

The contacts are closed on overload by the rotation of a disk actuated by a U-shaped driving magnet with shading coils on the pole pieces. No tripping current is carried through the revolving parts. When the contacts have been closed they are firmly held in that position until tripping occurs by the armature of a holding coil connected in series with the contacts, and by the trip coil of the air or oil circuit breaker and an auxiliary switch which opens when the breaker is tripped. This insures current on the trip coil continuously until the circuit breaker opens, and prevents flashing at the contacts, which, as an additional precaution, are of high heat-resisting metal, non-corrodible, and therefore practically indestructible. The current-closing capacity of the tripping contacts is extremely high for a relay of this type.

Changes in surrounding temperature will cause an induction time limit relay to act with a large variation in its time delay, if uncompensated for such changes. This relay is provided with an efficient temperature compensating device, which is another point of excellence in its construction. This device

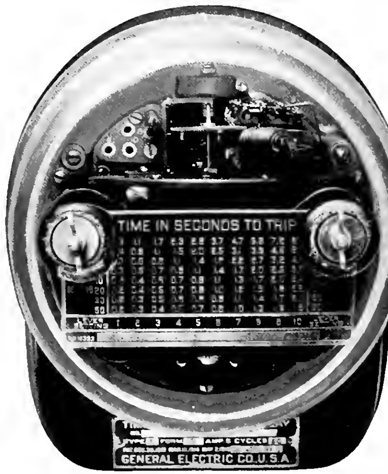


Fig. 1. Time Limit. Overload Induction Relay

keeps the time delay variations within reasonable limits.

The operating or characteristic curves for various lever settings are entirely separate and distinct at even the heaviest overloads and never become instantaneous, although the time lever can be moved to a position lower than No. 1 setting, making the time delay approach instantaneous action. This is because of the inherent characteristics of the relay, which produce a curve consisting of an inverse time portion up to approximately 2000 per cent of minimum contact closing current, blended into a definite time portion with a slight downward slope, Fig. 2. Consequently, the relay will do the work ordinarily required of both inverse and definite time relays. The heaviest overloads do not disturb the form of the curve nor cause vibration or chattering of the moving parts of the relay.

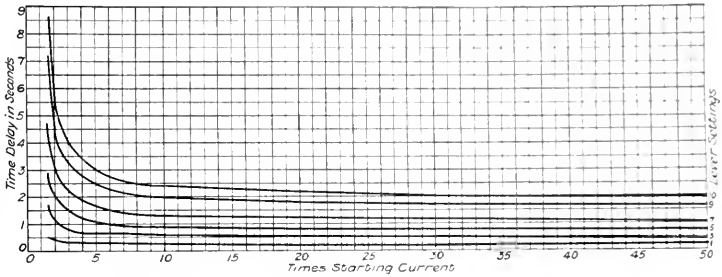


Fig. 2. Characteristic Curves of Relay for the Different Lever Settings and Current Taps

The adjusting lever, which regulates the angular travel of the disk and thereby controls the time element is just above the index plate, and has a scale with divisions from 1 to 10 inclusive for each of the corresponding numbered columns of time values.

For a given lever setting, the characteristic curves for all of the current taps are practically identical, as may be seen from a study of Fig. 2.

Current settings are made by inserting a metal plug in a current tap plate (shown in the upper left-hand corner of Fig. 1) which has taps for 4, 5, 6, 8, and 10 amperes. The current settings are obtained by cutting in proper portions of the relay windings.

The index plate bears 80 time values at 1.5, 2, 3, 5, etc., times the ampere values of the current tap. For example, with $1\frac{1}{2}$ times the current for which the tap plug is set, and with the lever setting at 10, the relay will trip in the time given on the index plate in the column numbered 10 and in row marked 1.5, regardless of whether the plug is at 5 amperes or any other current value. If for a particular current setting it is desired to set the relay to trip at some current the multiple of which is not listed on the plate, the required lever setting may be found very closely by interpolation of the "times current tap setting" value, with the time delays corresponding to it, in the various columns.

An instance of the thought that has been given to convenience of adjustment is illustrated by the spare current tap plug, located beneath the index plate. When a change of current setting is to be made with the relay in service, this spare plug is first withdrawn and screwed into the current tap of the circuit on which a change is desired. The tap plug previously in use is then removed from its setting in the current tap plate and placed in the receptacle for the spare. The change of current setting is thus made without opening the secondary circuit of the current transformer, which would otherwise have to be short-circuited, involving more or less time and inconvenience.

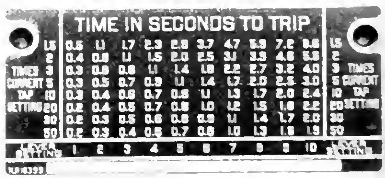


Fig. 3. Table giving Time to Trip for the Different Lever Settings and Current Taps

It is evident that these relays possess several advantages not heretofore obtainable in relay construction. They are the result of exhaustive experimental work and combine to a marked degree the qualities of accuracy, simplicity, and reliability.

The Demand for Greater Industrial Economy

By W. Rockwood Conover

Economist, Schenectady Works, General Electric Company

Under the existing state of world war and universal economic distress, it is essential that industry be organized on a higher plane both of efficiency and economy. Under the captions of Organization, Management, Designing, Production, Routine, Purchasing, etc., the author points out the urgent need for readjustment of industrial processes as a whole and the paramount necessity for conservation of all industrial wastes. This article appeared in part in the August number of *Industrial Management*.—Editor.

Industry is universally recognized as the natural foundation of human existence. It is thus both historically and coincidentally the economic basis of the state and of our national government. Nearly all human endeavor is measured by the visible evidences of material benefit derived from organized forms of productive labor. In time of peace industrial enterprise is an essential element in the development of the race, the upbuilding and growth of communities, the establishment of order, the stability and permanency of both state and national governments, and the conduct of private life. In time of conflict it becomes a vitally important factor in equipping and sustaining contending armies in the field, and the indispensable source of maintenance of the engines of war.

In the present world-wide strife and consequent disorganization of the normal functions of business it becomes imperative that all our industrial operations be placed upon a higher scale of efficiency and economy than ever before, in order to afford our government and allies the greatest degree of support and relief during the period of increasing universal distress. It is essential that manufacturers and managers everywhere institute anew processes of investigation and analysis in order to determine where they stand in the competitive scale of productive power among the industries of the world. Extravagance and waste and inefficiency have heretofore been nearly universal. Nowhere have invested wealth and capital attained a full measure of success commensurate with the possibilities involved, or produced results representing one hundred per cent utility of equipment and facilities supplied. Large resources have been devoted to industrial enterprise only to demonstrate that net earnings are not comparable with initial expenditures, and nowhere do we obtain the full benefit of human effort or the largest product possible through the consumption of labor and material. Many industries are handicapped by high manufacturing costs through failure to establish proper systems of economic control in all the functions of industrial operation. In many manufacturing plants there is evident a large degree of inefficiency and waste, coincident with which there usually exists a lack of co-ordination and co-operation in the functions of management and factory supervision. Losses and delays in production occur because of incorrect or incomplete designing, improper and inadequate distribution and supply of tools and materials to the shop, incomplete drawings and instructions to the workmen, and lack of care in authorizing and following out production schedules. To these add defective equipment, unsanitary shop conditions, and lack of interest in the individual, and we have the chief explanation of the universal decreased effectiveness of human endeavor and the inevitable curtailment of the volume of industrial product. Statements of the ratio between capacity and accomplishment in industrial undertakings are sometimes exaggerated and pessimistic, but one needs not to look far to perceive that too large a factor of the world's labor is expended in the consumption of man power and energy without a satisfactory commensurate return.

Organization

The organization of industrial undertaking will doubtless have to be developed along new lines. Industries will need to be established for more definite and specific purposes. The plans for founding new business or building new factories must give greater consideration to a proper differentiation between that portion of the product or apparatus which it is desirable to manufacture at the home assembly plant and those parts or details which can be purchased with greater economic advantage from outside concerns engaged in the production of small parts. Because of this fact it will be necessary to analyze more exhaustively the principal phases of proposed organization and all acts relating to the founding of a new industry in the beginning, in order to proceed with fully defined plans in reference to the nature and extent of the equipment required, lay-out and construction of departments and buildings, and the spaces to be alloted to receiving, shipping, storage, etc. Concentration of productive processes, of tools and equipment on the one hand, and segregation of manufacture on the other, must be studied in the relations which they bear to transportation, to available sources of supply, to advantages in making purchasing contracts, to productive efficiency, and coincidentally and directly to economic and profitable factory costs.

Management

The advanced principles of management and supervision must receive a new degree of attention, and more scientific thought and study must be given to the subject of co-ordination and co-operation of executive and productive forces. Greater concentration of authority and of all official acts, the elimination of repetition and duplication of directive effort, and the establishment of higher standards of operation involving greater speed and precision, and greater finality in all the rules of shop practice will be essential to meet the demands of progress both now and in the new industrial period that is before us. New standards must be set up as rapidly as new experiences have developed new knowledge and have demonstrated more practical methods of performing either official or mechanical work.

Designing

Our engineering and designing work will need to be more constructive, more final in its application to shop processes. The experimental stage of new designs will have to be wrought out and completed in a field or department by itself. The new order of things and the rapidity with which a new invention of public or private utility must be put into production will render imperative a greater degree of completeness and refinement in design than has heretofore been realized. When the shop starts work it must be with well defined plans and instructions, with no stoppage of productive processes through uncertainty or lack of information, and with the stamp of finality and accuracy upon every workman's drawing as he takes up each new task on bench or machine.

Production Routine

In the organization of production routine there must be a broader and more intimate knowledge of shop conditions, in order that the movement of materials in rapid, progressive order and sequence of operations may be provided for, and the delivery of separate details to the assembly floor with regularity and certainty accomplished. This will involve a more extended analysis of both human labor and shop equipment, a rearrangement frequently of men and machine tools, in order to systematize movements and secure greater precision of actions both manual and mechanical. It will involve a greater refinement of shop processes, the substitution of modern tools for old, of machine performance for manual tasks, and a general speeding up of all operations in effective unison of effort toward a common end. The old methods of handling production must be eliminated from present industrial establishments and the progressive shop of the future. The distributing of tools and materials, instituting schedules of output, or providing the workman with drawings and instructions, must be with such accuracy and promptness of service as shall render the application of all directive effort to manufacturing processes efficient and complete.

Production routine cannot be divorced from indirect labor in any analysis looking toward improvement in industrial processes as a whole. The systematic supply and movement of materials through successive machine and assembly operations are directly dependent upon the expense forces of the shop. The work of supervision, clerical routine, care of stocks, operation of cranes, and general floor labor, all bear a most important relation to the business of manufacturing the finished product. These forces need to be organized into units of proper size for harmonious action and co-operative effort. Careful supervision and patient instruction need to be given and the standard of service raised, and a higher degree of efficiency established the same as we demand precision and cohesion in mechanical work.

The departmental extensions and repairs, the upkeep of equipment and tools, and the providing of facilities of whatever nature necessary to the speeding up of productive processes, and the maintaining of ever higher standards of manufacture must be viewed by the manager in a new light under the new conditions, and must become more and more matters of his personal interest and care

Purchasing Stocks

The purchasing department has a new and added burden and a more difficult task to perform brought about by the world war. Many new problems are involved in obtaining the factory's supply of raw materials which did not exist three years ago. With increased cost of metals and fabrics other influences have combined to make the work of the purchasing agent hard and often impossible of result. Congestion and delays in transportation, requisitions, and embargoes by the government, increasing consumption and demand in every part of the world, all tend to render the obtaining of stocks more and more a matter of uncertainty and often one of mere speculation. With these increasing difficulties greater effort must be made, not only to find new available sources of supply, but to conserve and save in the purchase and use of everything required by the shop. Systems of control must be set up in every department and rigid rules of economy established which shall make impossible the improper employment or destruction of anything of inherent value. This will involve the instituting of new methods of procedure in most factories, for as a nation and as individuals we have not yet taught ourselves the full lesson of economy either in the administration of government or of industrial enterprise. We are predisposed to extravagance and waste, to inordinate desire to have everything in abundance, to the consumption of many material things which cannot be demonstrated to be of essential value to either our physical wellbeing or our mental advancement and growth. Not only productive stocks but expense supplies and materials for maintenance of equipment and for the prosecution of daily office and shop routine must receive greater attention than in the past, and new practices established which will limit and conserve the use of these materials within the bounds of carefully regulated and scheduled manufacturing requirements.

Receiving and Shipping

In the functions of receiving and shipping, preparations must be made for handling a large increase of tonnage, both incoming and outgoing. This will make necessary larger and better facilities for loading and unloading, more trackage for rapid, systematic movement of cars, and extensive systems of conveyors throughout all departments and shops. Storage areas will need to be increased and larger buildings provided, both for incoming raw stocks and for finished product ready to be shipped to outside markets.

Power Production

The production of power, heat, and light is a field demanding special attention at the present time. It offers new opportunity for vast improvements in the type and character of installations, and a higher degree of economy in operation. The present fuel shortage lays new emphasis upon the need for more investigation and study on the part of manufacturers and managers into the cost of electrical energy and of steam for heating and manufacturing purposes. New stations will have to be built and extensions planned to provide for large increases in generating capacity. The old equipment of engines and boilers must be rapidly superseded by modern apparatus before power can take its proper place among other functions of industry already engaged in the conservation and building up of the world's resources. There must be immediate recognition of the need for more efficient installations from year to year, more scientific methods of operation, and better systems of control of consumption in the shop in order to keep pace with the present and future growth of industrial supply and demand. If factories are to win the war, it is essential that they be supplied with and supported by abundant sources of power.

Conserving Industrial Wastes

The conservation of by-products and waste is now forcibly brought to our attention by the exigencies of the great struggle going on. There now exists a paramount necessity to save everything of inherent value which cannot be ignored or gainsaid. It is becoming pressingly evident that we must reorganize our present practices in business and manufacturing to meet the new conditions or suffer ignominious defeat. The gigantic strides of industry, the growth of new communities, the wealth of big cities, and the world-wide demand for products, have all tended to develop a confidence in our abounding resources and a habit of wastefulness in our production. This tendency has been conspicuous in the building and operation of railroads, but it is also evident in the operation of manufacturing plants as well. Contiguous areas between shops, as well as factory floors and store rooms, show accummulations of metals and other materials left over from productive processes or from the work of maintenance and repairs. Lack of time and reduced labor forces make it convenient to leave the disposal of these materials to some future date. Successive inventories frequently show lists of parts held for possible supply orders which could judiciously be turned into the scrap market at advantageous prices and thus aid in maintaining the country's supply of essential metals. Comparatively few industries are free from these accumulations and few realize the extent of the loss entailed through neglect to save and sell their by-products systematically, as an important part of business. It is essential now more than at any previous period in the history of manufacturing that industrial managers give a fuller consideration to this most vital of factory subjects. The needs of our national government and of the world at large, both during the present struggle and for decades to come, will make imperative the universal establishment of systems of conservation which shall render impossible the loss or destruction of anything which can be put to private or public use.

Human Labor

The factor of human labor has assumed a new and most important place in all industrial operations. During the present world conflict its importance has multiplied a thousand-fold. Neither the work of private industry nor the manufacture of materials for war can be carried on without the co-operation of the individual and of skilled labor as a class. Every productive process is dependent directly or indirectly upon the constant application of human energy, mental or physical. Now, as never before in the world's history, nations and governments are looking to industry to do the greater share in the world's fight for peace. And what does it all mean? It means that man-power at home is as big as man-power in the trench. It means that economy of effort and precision in action are as important in the factory as science and discipline on the fields of battle. Conserving human energy and devoting it to the business of the world's production must be accomplished by training and study just as definitely as we train for the scientific practices of war New methods in the employment of help, adapting men to tasks for which they are fitted, training them for higher service, instructing them in economy of physical strength, educating them in the maintenance of health and comfort and safety, are all problems of management which emphasize the greater responsibility of the nation's immediate future.

It is essential that the highest accomplishments possible of attainment shall be realized in all industrial enterprise. The call is to industry. If we are to attain the freedom of the world it must be through a higher refinement of man-power—a fuller degree of perfection in manual and mechanical art. Systems of control must be set up in every factory in the land, analyses of all manufacturing operations, of official and directive functions, of every detail process of production instituted, which shall make possible the highest degree of perfection in all human endeavor.

Some Notes on Office Equipment and Methods

By C. M. Ripley

Publication Bureau, General Electric Company

Engineers frequently have thrust upon them problems in office arrangement and management, especially when they undertake work of an administrative or executive nature. It is just as necessary, therefore, for an engineer to be informed upon the subject of efficient office methods, as it is for a commercial engineer to know how to establish and maintain favorable relations with his customers. If the following article does nothing more than stimulate interest in this subject and quicken the readers' powers of observation, it will have fulfilled its purpose.—Editor.

In my visits to various offices and factories it has been my good fortune to see in operation and have explained to me many clever schemes for simplifying work, for saving time, fatigue, and annoyance, and for furthering convenience. And when I say, save time and fatigue and annoyance, I don't necessarily mean clerk's time and fatigue and annoyance, but everybody's. There is no reason why the same principles which assist production in a factory, and help a man to earn more and turn out more work with less effort, cannot be applied to office work; so that an engineer, an executive, or a manager can do the same work with less strain or do more work with equivalent or even less effort than before under old arrangements.

One thing that I was impressed with was the fact that a great many of these schemes are intangible, evasive, and hard to discover. This applies particularly to office "atmosphere" — impressions of exquisite order, simplicity, and the reduction of equipment and furniture to the bare essentials. In some of these cases the atmosphere is due chiefly to the absence of ordinary untidy or conventional office equipment; and again some of these impressions are merely the result of the scarcity of equipment, which is generally visible in quantities.

In a great many ways office equipment and arrangements suggest those of factory, and experts in laying out an office now locate each desk, card index, typewriter, table, bookcase, and filing cabinet with as much care and forethought as the production expert places the drill presses, lathes, overhead cranes, etc., for it permits him to route the material from one end of the office to the other in an approximately straight line.

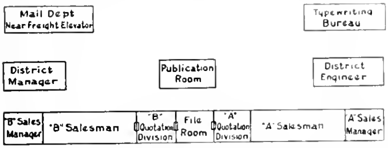
In an office, as in a factory, special machines are used for special processes: the adding machine, the phonograph, the tub desk, etc., are just as important to the office as the machine tools are to the factory.

An office, the equipment of which has been reduced to a minimum, impresses the observer much as does a soldier's equipment—nothing unnecessary. The soldier does not carry with him things that he uses only once a week or once a month, but only those things which he uses every day. One reason for this is that he is told what he should carry; and the other equally potent reason is he does not carry unessentials because it is *he* who must bear the extra weight; whereas in the business or industrial world it is the *company* which carries the burdens of unessentials.

It is no more absurd for an engineer to compile, preserve, and maintain data to be used once a year, and which could otherwise be found in five minutes, than it is for a soldier to carry a bathrobe, a private bath-tub, and a pair of velvet slippers. The expense of obtaining and maintaining such "data" does not fall upon the engineer, and he is continually being tempted to make a great many useless jobs for other people because of the sincere belief that he will use these data frequently; whereas, in fact, he will but seldom consult his much treasured archives. An engineer in one of the largest and busiest sales offices in the country made the claim that in the old days he maintained an elaborate card index which he thought he used frequently and which cost the company approximately $300 per year to maintain. By observation he found that he used this perhaps only once a month or less, and that whenever needful, he could find the same data by another method at an entire expenditure of but five minutes of his own time. He saw the folly of the old arrangement and abolished the record.

The essential error in the minds of those who maintain useless records, papers, data, and files, is that they sincerely believe they consult them about every day, whereas repeated investigations show that such files, etc., are frequently not consulted once in weeks or even months.

An engineer executive recently remarked: "We have a place for everything essential, even your hat." He proved that four office boys in his office were essential instead of twenty-three; that four files were essential instead of twenty-two sets of files in nineteen



Ideal Arrangement of a Sales Engineering Office Handling Two Types of Business—(A) and (B). Note the central location of the file room and the publication room. "The typewriting bureau could be anywhere, as only the office boy goes there."

different places; that seven card index systems were essential instead of twenty-five sets: and that one complete file of publications in binders was essential, where formerly there were fifteen complete sets, all of them kept up to date, making useless jobs for useless workers.

This phase of saving the time of engineers and executives is not often written up in books on office management and systems, at least not so far as I have ever been able to see. These books generally explain how executives should direct subordinates; but the idea of abolishing jobs, and hence useless workers, seems to have been untouched in the realm of business literature.

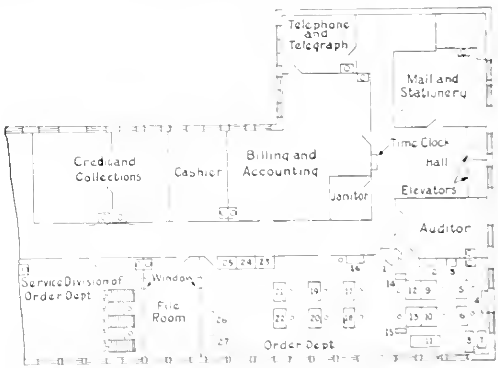
Two methods of eliminating useless work are, first, to do away with the job, and second, to substitute labor-saving devices.

Some moves in this direction are really cumulative. The reorganization of a large sales office resulted in sending several carloads of data back to the home office. Instantly the furniture necessary to store the data became unnecessary and the services of the employees compiling the data became available for other things. The one bold stroke of abolishing the data eliminated many useless jobs, and at the same time provided more floor space.

Refinements in Telephone Service

When telephoning to a certain Philadelphia office, almost before your inquiry is made, the telephone operator will say either: "I will connect you," or "Mr. Wilson is not in." This speed is made possible by a bank of lamps at the telephone girl's elbow, one lamp for each man. If the light is on the man is in: if the light is out, the man is out. The lamp for each individual is opposite his name. These 72 miniature green lamps are on an indicator board 20 in. square, set practically on a level with her eyes. Upon the arrival of each individual, his lamp is lighted by the hall boy, who inserts a plug in the proper socket; when the individual leaves the office, the plug is removed. One inquirer was skeptical of the reply, owing to the speed with which the young lady answered his question. He said, "How do you know so quickly that Mr. Wilson is out? You have not had time to ring him and get an answer." He was suspicious until she explained how the speed of the service was obtained. In this telephone room there are three girls who operate a two-position switchboard, and one who typewrites, codes and decodes telegrams. Each girl can do all of this work and they change places to avoid fatigue

There are several other devices in connec-



Plan of a Portion of a Philadelphia Office showing how the File Room is Adjacent to the Two Sections of the Order Department and also close to the Credit and Collection Department, Cashier's Office and the Accounting Department.

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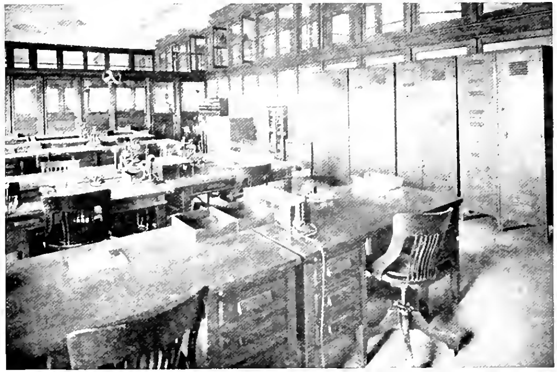
tion with telephone service that are well worth noting. In Chicago a salesmen's room has nineteen desks and ten 'phones. When a call comes in for a man who is out of the office it is unnecessary for others in the office

The Symmetry of this Office is maintained by the Use of "Floor Cleats" which Hold the Desks Exactly in Position. Every employee in this Pittsfield office sits facing the manager's office



Simplicity and Neatness of Almost a Military Character. Note metal locker, racks for rubber stamps, and the "cleaned-up" appearance of the flat-top desk

The "Vest Pocket" Switchboard used in a Chicago Office. This reduces noise in the office due to unnecessary ringing of telephone bells, and permits an outsider to be held on one telephone wire while information for answering the call is obtained on another wire

Orderly Arrangement of a Salesman's Office in Philadelphia. Note the phonographs, name on the right-hand upper drawer, and absence of telephone directories, waste paper baskets, etc.

to answer his telephone. A young lady sitting in the reception room of the manager's office, in full view of the entire room but back of a glass partition, has before her a miniature switchboard which shows a light at every incoming call for salesmen. If this light is not immediately extinguished she knows that this salesman is not at his desk, and she answers the call, informs the inquirer accordingly, takes the message, if any, and goes so far as to make appointments in some cases. This memorandum is put on the salesman's desk.

This arrangement overcomes one of the objections to the large room for the salesmen and specialists, as no one is compelled to answer the other man's calls or endure the long and repeated ringing of telephone bells.

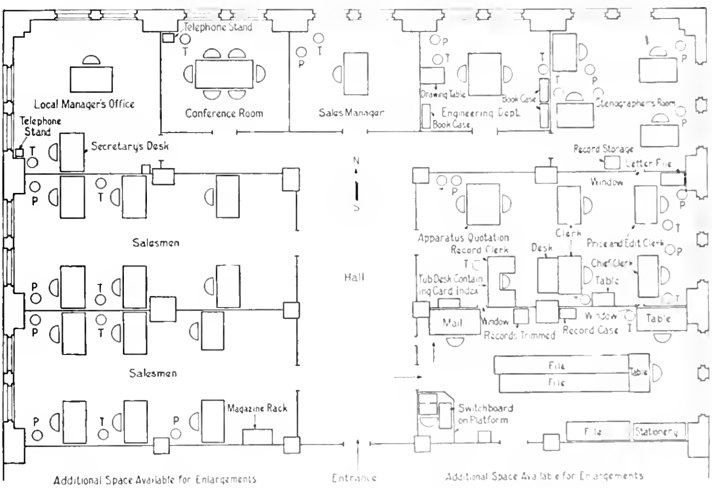
Every desk in another salesmen's room is equipped with a small switchboard which requires little more space than an inkwell. This switchboard permits any man to answer any other man's telephone call. More than that, they can hold an outside party on the wire, and with full privacy call another party with the same instrument.

In a Philadelphia office there are direct private telephones between the quotation men and those stock clerks in the order department who have charge of the card indices showing stock in warehouse. This arrangement saves a great deal of time for the quotation men, as they can rapidly ascertain what apparatus is in stock.

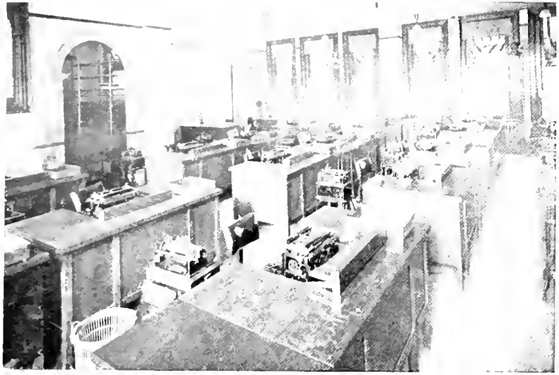
In a Chicago office a telautograph is installed between the order department and the warehouse. This installation was made not only to get rapidity but extreme accuracy in rush shipments Since double records are made of all orders transmitted, it is a very easy matter to establish responsibility for any errors which may have occurred.

A Los Angeles office provides what they call instantaneous telephone service, whether a man is in his own office or another.

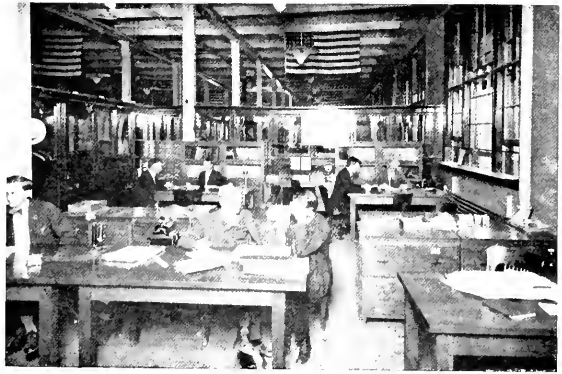
The telephone operator, because of the glass partitions in the office, is able to see at one glance every corner of the office, and if the individual called is visiting some other official, or is in the conference room, she can at once reach him by telephone.



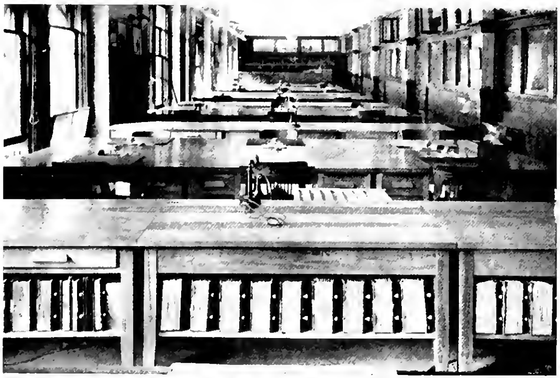
This is the Layout of a Model Baltimore Office, showing the Location of Every Piece of Furniture. Every telephone is indicated by the letter "T" and every phonograph is indicated by the letter "P". These were all shown on the layout before the office was equipped. There is no furniture in the office which is not shown on the layout and every piece of furniture shown in the layout is installed in this office.



Stenographic Room at a Large Philadelphia Office. Probably 90% of this dictation is due to the phonograph



A Schenectady Office with Ediphone Dictation, and Special Furniture. Note the tables instead of desks. Letter files and card index cabinets are used for table space, all within easy reach



Attractive and Efficient Arrangement of the Cost Department of a Large Factory Office in Schenectady. This room formerly had high sloping desks at which the clerks sat on stools. Note that the tables and desks alternate and by wheeling around in the chairs the clerks can obtain access to books and large drawers of cards in addition to telephone and large working space

The Twenty-five Stenographers in this Room in a Large New York Office Greatly Appreciate the Felt-ceiling which Eliminates Noise and Makes Operation of the Phonograph More Easy

The telephone operator also keeps an indicator arranged along the lines of a cribbage board, on which can be indicated the time each man leaves, the time he promises to return, and in many cases where he is. A preceding photograph shows how the glass partition assists in providing this instantaneous telephone service.

Reduction of Noises

A world-famous automobile manufacturer of Detroit requires that all office employees talk in a low tone of voice. This permits of low partitions reaching only to the height of the wainscoting and often no partitions at all. The ventilation is thus improved in the office and the effect upon visitors is most agreeable.

The occupants in the office are likewise delighted with the arrangement and would not go back to the old thoughtless style of talking, as the new plan has entirely won their admiration. Those who have long distance calls, when it may be necessary to talk louder, are requested to use a telephone booth conveniently located for that purpose.

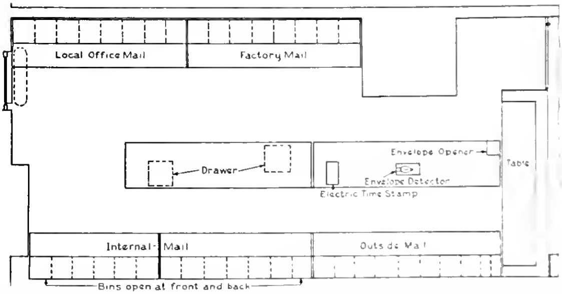
One of the most interesting things about a large New York office is the sound deadening effected in one of the salesmen's rooms, and in the typists' room where the phonograph records are transcribed.

In the salesmen's room are desks for thirty-four salesmen, with a telephone extension for each. On entering the room one is struck by the quietness. The floor is covered with linoleum and the ceiling with acoustic felt.

It is a queer thing about noise; noise is cumulative. If you lessen the general noise, each individual can talk lower and be clearly understood; and the lower each individual talks, the less general noise there will be. Contrast the situation of groups of men talking in a low tone of voice with the old fashioned bedlam in an office where you are actually shouting in order to be clearly understood. The louder the noise of the typewriters, telephone bells, dictation, etc., the louder we must talk in order to be understood, and the louder we talk, the louder the general noise, and so on throughout the vicious circle.

In this room, however, there is no general noise. I was amazed at the low tone of voice which could be adopted in conversation.

And then, imagine entering another room with twenty-four girls operating typewriters and finding it as quiet as an ordinary office with but two machines going. I think all would be inclined to agree that quietness makes the same contrast with noise that order makes with confusion and disorder.

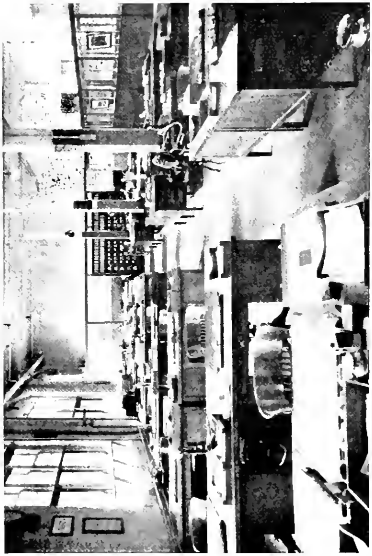


Plan of the Mailing Department in a Large New York Office. Note the envelope detector, envelope opener and electric time stamp. The internal mail boxes are open front and back as explained in text.

Another interesting thing in connection with a salesmen's room is a small service switchboard without cords or plugs, which supervises the thirty-four telephones in this room. When a man leaves the office he so informs the special service operator at this switchboard and she throws the switch under his name, to the off position. Then when a call for this individual comes in, whether from inside or outside of the office, his bell does not ring; but a lamp lights on the switchboard above his name and the young lady informs the caller that Mr. Blank is not in, takes the message, makes a memorandum, etc.

Another valuable arrangement in connection with telephone service in this New York

Clear Glass Partition in this Los Angeles Office, Permit the Telephone Operator to Give Instantaneous Service. Note elevated switchboard on left



Simplicity Neatness, Strictly Business, Clear Glass Partitions Add Considerably to the Appearance of this Office. Note the phonograph

The Stenographers' Room in a Baltimore Office. The phonograph records are passed through the small window in the glass partition

A Model Filing Room in a Philadelphia Office. Window in the background leads to the quotation division and window to the right permits publication to be delivered to callers in the hall office was provided for especially busy phones where outside inquiries must immediately be met with return information. Two separate circuits are run from the switchboard to a two-way switch under the desk of the busy man, and within easy reach. This permits the user to hold one outside party on the line and with the same instrument call up the warehouse or other party in or out of the office, obtain the desired information, and then return to the original inquirer with the complete information. A three-way connection can also be made so that three persons, two inside and one outside of the office, can hold conversation.

The Mailing Department

In this New York office, the mail room is a model. The mail force comes on at 8 o'clock in the morning and by 8:45 there are 3000 letters lying on the proper desks, part of them open (the personal ones unopened), all stamped with the day, hour, and minute of their receipt.

Four special features constitute the main points of interest in its equipment. They are:

First, a motor-driven envelope opener which saves three hours a day, chiefly in the morning. The maker claims that it will open 350 envelopes per minute, and on test it opened 97 envelopes in 17 seconds. It has been used a year and the blade has never been sharpened. It is built on the safety principle and is not dangerous to operate. This little opener is located at one end of a handsome steel table with linoleum cover, neatly brass bound on the edges. In the middle of the table is the second feature, the envelope detector, by which at a glance the clerk can make sure that the envelope is empty. This is nothing more nor less than a piece of strong glass set flush with the table top and provided with an electric light under it. Each of the several thousand envelopes is passed over this glass before discarding.

The third feature in this clever arrangement is the electrically operated time stamp, which is set flush with the other end of the counter. The time of opening the mail is registered without raising the letter from the table. This is operated by the master clock, and the day, hour, and minute are all automatically changed and recorded.

The fourth element of interest in this model mailing room are the steel racks containing the compartments for the mail. This rack is in four sections, arranged as follows:

(A) 64 compartments for large customers.

(B) 80 compartments for the company's factories and offices.

(C) 96 compartments for internal distribution inside the New York office.

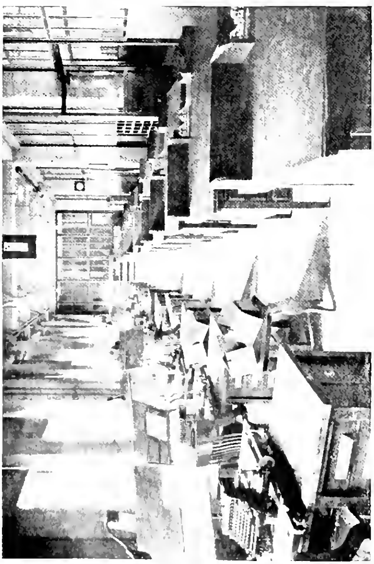
(D) 24 small compartments arranged alphabetically for grouping letters to go in the same envelopes, but for customers not large enough to warrant a large compartment as in the "A" class.

As to how much postage is saved by grouping the letters together, an experiment was conducted over a period of six days, three of the days under the old system and three under the new system with the new bins. A careful record of the postage during these two periods indicated a material saving for the latter method.

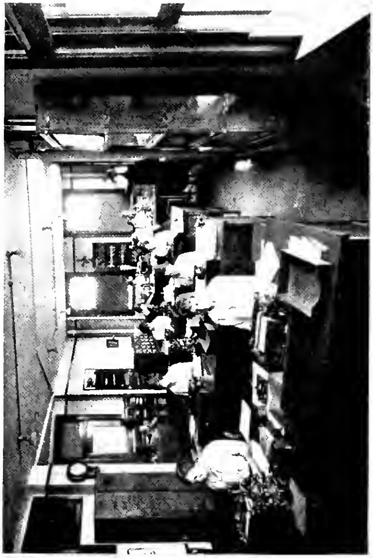
The internal mail is handled in a very clever method, where the boy delivers as he collects, and sorts the mail en route. This amounts to a direct internal mail service; and with hourly trips the necessity of many visits and telephone calls is eliminated. This system greatly expedites the mail, as it is unnecessary for it to be taken to some central point.

The sorting of the inter-office and factory mail to save postage and envelopes has been extended to include several of the largest customers, whose letters are grouped together before being put in the envelopes. Envelopes are kept in stock, addressed to these firms. Examination of the contents of one compartment showed that six letters addressed to one concern for that day were mailed in one envelope at an expense of 6 cents in stamps, where if they had been sent separately it would have cost 18 cents and six envelopes. The envelopes for these large customers are addressed by an addressing machine.

At a Cleveland factory a "local mail service envelope" is used, having the dimensions of $4\frac{3}{4}$ x $10\frac{1}{2}$ in. This is made of rather stiff manila paper and has on each side lines for 26 different addresses. This could therefore be used approximately 52 times, unless worn out before. Four 7/16-in. holes are punched in this envelope so that it can be seen at a glance, without opening, whether there is anything in the envelope, thus saving time, errors, and stationery.



Symmetrical Equipment for Ledger Writing and Billing. Note special equipment for holding copy and holding pages of ledger with carbon copy included



A Busy Philadelphia Office Where the Customer's Orders Follow a Straight Path from One end of the Office to the Other. All dictation is to the phonograph, but the typists are writing requisitions. This office is shown in diagram elsewhere

Publication Display Fixture in a Philadelphia Office. Several thousand publications are made visible in a floor space approximately 3 by 12 feet, and arranged according to products sold by the Company

View of the Mailing Room Showing the Distribution Racks for Outgoing and Internal Mail. Note proximity to the table on which these letters are opened. The internal mail boxes are open at the rear end so that the mail boys can remove the mail without interfering with the employees in the mail room

The Service Letter

The service letter is a form of stationery for letter writing and answering that was developed in a Chicago office, and one which, I predict, will be very extensively used in the future.

We have all received letters similar to the following:

"Dear Sir,

Referring to your letter of the 18th ult., I answer your questions as follows:

1st– 24,000.
2nd– $8\frac{1}{2}$
3rd– $19\frac{1}{2}$ per cent for 1917.
4th– No.
5th– No.
6th– Yes.

Very truly yours,"

The point is, I have to look up a copy of my letter to this individual last month and find out just what questions I asked him. By using the service letter, however, a copy of my original letter containing the questions will be on the back of his reply. The sheet of paper is folded on the center line and the carbon placed between. When my letter is mailed, a sheet of paper is also attached for the reply, and on the back of it is a copy of my original letter. Therefore it is easy to send, easy to receive and understand, and it materially reduces the expense for the stationery for an inquiry and answer.

An incidental advantage, yet an important one, is that the users of these service letters get in the habit of writing in telegraphic style, that is, using short words and short sentences, and omitting all unnecessary words. This encourages short letters and also prompt answers. Moreover, it is war-time economy, inasmuch as both sides of the paper are used at both ends of the line.

Combination Envelopes

The Pacific States Company has recognized that it is often desirable to have bulletins received by customers in the same mail that brings the accompanying letters. The correspondence division of that office has been accomplishing this result by pasting the envelope containing the letter on the outside of the bulletin envelope. This combination requires first-class postage on the letter envelope, and third- or fourth-class postage according to weight on the bulletin envelope. This combination conforms to postal regulations.

The Business Phonograph

The present great demand for stenographers has resulted in greatly increased use of this instrument for recording dictation and through improvements in the instrument and a study of the organization of the transcribing department much of the old objection to this form of letter writing has been overcome. Undoubtedly the greater part of the correspondence of most firms can be handled successfully by the phonograph, and its adoption certainly goes a great way toward eliminating distracting noises and conserving office space.

At one large factory a total of 385 phonographs are employed in seven departments. Specific information as to the square feet of floor space saved by their employment has not yet been determined, but a conservative estimate would place the figure at 15 per cent, which is the equivalent of an additional story or two in a modern large office building. The popularity of the phonograph is largely dependent upon the service interval that can be obtained, by which I mean the time between dictation and the receipt of the typewritten sheets. In some offices by careful organization and practice a two-hour service is maintained, and on occasions this can be reduced to one and one half hours.

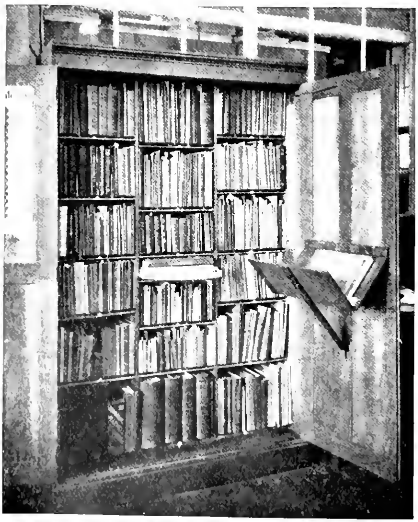
Professor Hollingsworth of Columbia University has made a study of mental concentration on the part of dictators, and the results show that human beings disturb concentration more than any other object. Hence we should expect a better form of composition and a greater degree of accuracy from phonograph dictation. The elimination of noise from many typewriters operating in one room is of decided assistance in this respect. Even in the transcribing room, with proper attention to sound-deadening construction, the noise can be reduced to a very great extent. In a Chicago office, 24 typewriters in one room make less noise than six machines in the average room. This result is accomplished by covering the ceiling with sound deadening material.

From an economical standpoint I might mention that the auditor of one Chicago office states that the business phonograph has saved in the one office over $20,000 a year in salaries. The cost of the standard machine is low, and it occupies $1\frac{1}{4}$ sq. ft. of space on floor or desk.

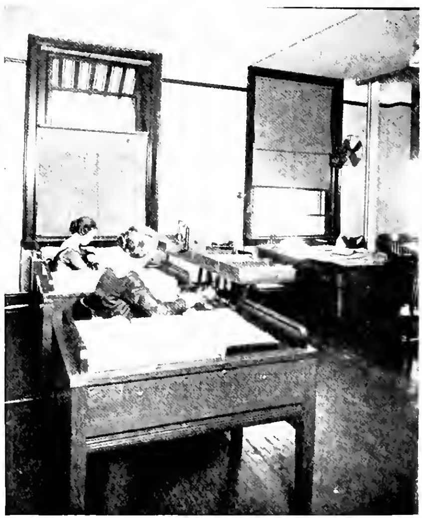
At a large factory office where several desks are close to each other, all used by men who have phonograph dictation, the practice is being adopted to wiring the desks for the phonographs. The wires are run through a conduit, and when the desks are put immedi-

A Blueprint Filing Cabinet Designed for a Philadelphia Office. It is a great time saver and also minimizes damage to large and small prints

Bag for Rapid Distribution of Internal Mail. The boy collects when he delivers



A Catalogue Filing Cabinet that is a Prize-winner. Note the different sizes of books and periodicals that are neatly filed. Also the racks for consulting them. This is in a Pittsfield office



An Interesting Example of a Tub Desk. Note also the fixed mail boxes on an elevated position on brackets. Phonographic dictation is used exclusively in this office ately adjacent to each other and almost touching, the plug is inserted into its socket automatically and the connection is established through the desks to the outlet of the wall. This could be worked with five or six desks in a row without the least disadvantage. This makes the desk easy to move whenever desired and yet lessens the confusion and tangle of wires which might otherwise exist, and it also prevents tacking wires underneath the desks, or running them along the floor.

Furniture

Until very recently it has been considered that there was little choice in office furniture, and that a table, a desk, a letter file, and a chair constituted the main elements of office furniture, the bookcase being frequently added. As a matter of fact there are today available a great variety of different types of furniture which are more exactly adapted to the peculiar needs of an individual office, just as particular machine tools are needed for certain work in the machine shop, or wood-working machinery in the workshop, etc.

The photographs show how special or "combination" types of furniture, now obtainable as standard equipment, can be used to exactly fill requirements, and result in less pieces of furniture in an office.

A New York office, which recently moved to the Equitable Building and re-equipped with furnishings, devoted a great deal of thought to the subject of the design of the furniture and the desks, chairs, etc., and also adopted a standard for the average desk for clerical work, and also the typists' desk.

The desk itself, as adopted, has a linoleum top and is constructed with four legs. It is thus easier to swing in and out from your desk without hitting your feet on the legs, than it was with the 8-leg desks formerly in use.

Everyone who uses the linoleum top is pleased with it; it is a nice, smooth surface, and as one man said of it, "You could spill a pint of ink on the desk, leave it there for a month and then clean it off."

The flat top desk is generally adopted. The tendency in selecting desks seems to be to have smaller desks and a lesser number of drawers. The evolution appears to be working towards tables instead of desks. This will be seen as we note the old-fashioned desks with eight legs, seven drawers below the working level of the desk, ten drawers above the desk in the old roll-top desk, and close to twelve pigeon holes. This makes quite a notable contrast with a flat-top desk with four legs and three drawers.

By lessening the number of drawers and adopting a flat-top desk, the user is considerably assisted by having a standard of arrangement—a place for everything.

The sketches herewith show the arrangements recommended in the large New York office. In the typists' desk the pins, paper clips, erasers, and pencils are in a tray which slides over two compartments in a drawer. In these two compartments are kept envelopes and personal belongings. The stationery, the old carbon, the new carbon, the blank forms, etc., are all in a certain definitely established location. These typists' desks, by the way, are also made with only four legs, and the typewriters are not placed on disappearing carriages but are set at a low elevation, and are covered by a rubber cover at the end of the business day.

A large insurance company in Hartford formerly used desks 60 in. by 36 in with eight legs and seven drawers, and they now use desks 50 in. by 30 in. with but four legs and three drawers. This reduction in the storage capacity of the desk prevents the accumulation of data and correspondence in private desks, which are really the property of the company and should be separately filed. In one large company there has been organized a "clean-out" committee which at irregular intervals after business hours goes through the desks and puts on top those papers which are not personal. This hint to the owner lessens his habit of keeping company papers in his desk.

Furniture experts believe that the table, which is frequently used in connection with the desk, could generally be eliminated, often to the advantage of the individual who has been using it. The argument that private papers must not be seen by the callers is a valid one, yet a simple habit can be developed which will easily obviate this disadvantage. After reading letters they can either be immediately answered and placed in the filing basket, or those awaiting attention can be turned over on their faces. One expert made the remark that a man who has a large number of private papers on his desk at the same time is getting behind in his correspondence If he were to organize his desk and have folders for matters needing immediate attention, and other folders for those which are awaiting further information, these could be placed in the letter-file drawer of his desk and the result would be an improvement not only in his work but in the appearance of his desk and a resulting increase in his mental concentration

A model office need not be in a modern office building. The Witherspoon Building in Philadelphia was built in 1896-7, and the Monadnock Building in Chicago was built about the same time, possibly a year or two earlier, so we can have a modern office without a modern building, for each of these house splendid offices.

When it comes to furniture, we can have a modern office with a minimum of furniture. In fact, the most modern thing about a model office is the elimination of furniture rather than the amount of it. With the introduction of the phonograph we automatically omit a table, a chair, and a stenographer, considerable locker space and the file cabinet, for the file basket and the central filing department are substituted. Moreover, the elimination of personal data goes far towards discarding the bookcase. A flat-top desk eliminates the pigeonhole. The habit of clearing off these flat-top desks at the end of the day's work eliminates piles of papers and books and correspondence, and common sense eliminates popular magazines, personal books, newspapers, and stacks of similar rubbish and the furniture necessary for housing or hiding them.

I have stated above that the immediate causes of atmosphere are often hard to discover, evasive. In fact, in order to find out how the extreme cleanliness, order and simplicity of an office is obtained, it is even necessary sometimes to get on your hands and knees in order to see how the telephone directories are hung on the inside of a desk so as to be invisible and yet available. Under the salesmen's desks in one Philadelphia office is a small hook upon which they hang their bags containing handbooks and other data. Also, perfectly hidden under some of these salesmen's desks is a strip of thin wood which serves as a book shelf, entirely invisible unless one's eyes are practically on a level with the chair seat, but within arm's reach.

The tub desk is a special desk for card indices which makes them handier than when on top of the desk, an arrangement which makes them too high to be convenient. The tub desk is coming into general use in the metropolitan offices and is quite valuable where large or small cards must be frequently consulted or written upon.

In the order division of a Chicago office there is a revolving pedestal on the top of one desk occupied by three men. On this pedestal are twenty-two card indices which can be revolved and consulted by each of the three men without leaving their seats. In a Philadelphia credit department they have a revolving pedestal with six drawers holding card indices so that two men sitting on opposite sides can use them.

The little item of having the rubber stamps on a rack rather than in a drawer saves a great deal of time in opening and closing the drawers and picking over a bunch of inky stamps before finding the one desired.

Publications

A well-organized library and publication room, complete and symmetrically furnished, exists in a Boston office. The most important engineering papers are well displayed in a rack, and handbooks, proceedings of engineering societies, and publications of all kinds are either neatly displayed in harmoniously designed bookcases or are filed in cabinets along the walls.

Visiting

All big organizations have encountered the visiting nuisance and some of them have solved the question once and for all. Department managers and section heads who are unable to keep their employees at their desks should protect other departments who are making a sincere effort to attend to business eight hours out of the twenty-four. It should be remembered that there is a triangular situation in connection with this visiting nuisance, as follows:

First, the visitors;

Second, the visitees;

Third, the other individuals in the offices who are disturbed by the conversations, and who might be called the innocent bystanders.

When an employee enters a new line of work, it is quite general that the motives are of the best and that he or she intends to give honest service in the new position. However, as time goes on the social element begins to assert itself and under one pretext or another the visiting begins. Authorities on such subjects claim that the responsibility is not so much with the employee as it is with the manager of the department where the employee is located.

These points should be seriously considered, if only for the time lost by those in the office who are compelled to listen to the conversation.

In one case a young lady's reason for leaving five minutes out of every hour was that she was operating a heavy billing machine and physically was unable to stand the work. In this case she was transferred to other work more suitable to her strength.

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VOL. XXI, No. 11

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NOVEMBER 1918

ELECTRIC FURNACES PRODUCING ARTIFICIAL ABRASIVES
These electrochemical abrasives are much more effective than the emery formally imported from Turkey

AMERICA'S PROGRESS IN

ELECTROCHEMISTRY

General Electric Review

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE   Associate Editors, B. M. EOFF and E. C. SANDERS   In Charge of Advertising, B. M. EOFF

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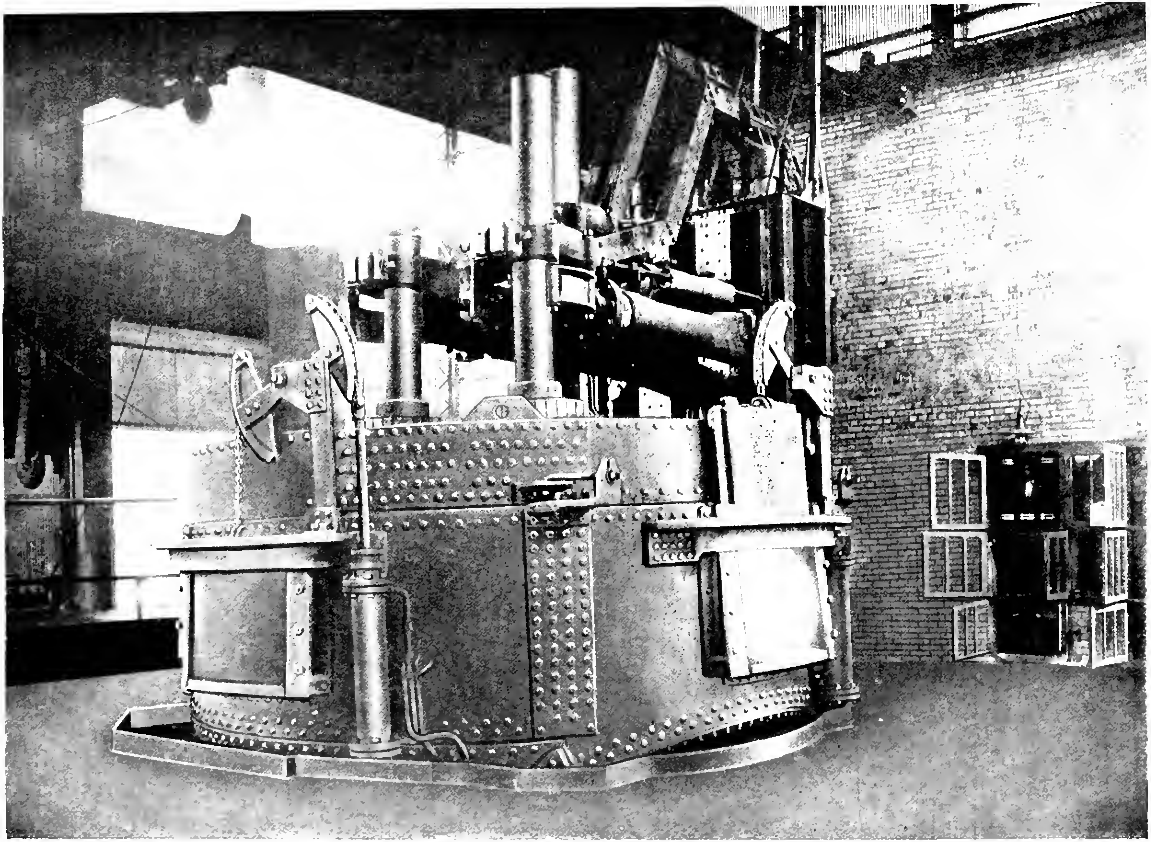


20-ton, 3-phase Hercult Electric Steel Furnace Fitted with Three 12-in. Graphite Electrodes. (Electric Steel Furnaces, page 767.)

GENERAL ELECTRIC REVIEW

AMERICA'S ELECTROCHEMICAL SUPREMACY

Of the commodities imported in quantity by this country before the war, it is perhaps safe to say that we were least prepared to manufacture commercially those products formerly obtained from Germany's chemical industries. Practically all of the finest dyes in use up to 1914 were imported from Germany; its chemists introduced and perfected the long list of modern photographic developers; and from the same base from which these dyes and developers were evolved, namely coal tar, a formidable array of industrial chemicals, synthetic perfumes, and pharmaceutical products were manufactured and extensively marketed throughout the world. Coal tar products are also essential factors in warfare, and these huge chemical plants and research laboratories were in reality military institutions heavily subsidized by the German government, secretly conducting intense research for war while openly converting war-time raw material into harmless but exceedingly useful dyes, medicines, and chemicals.

These German industries were thus enabled to market their peace-time products in foreign countries at prices that, as we now see it, were intended to stifle chemical research and industrial development outside of Germany—and with fair success.

But the war has changed all this. During the past four years the chemical industry of America has undergone phenomenal expansion; the war has forced the chemical industry to find itself, and it has likewise opened the eyes of the country to the fact that this great industry exists, is an indispensable factor in the war, and will be a wonderful national asset in the period of peace which is to follow. America's chemical industry is pitted against that of Germany in this struggle, and full conviction that the American chemist is equal to the emergency was forced upon all who visited the recent National Exposition of Chemical Industries in New York City.

Of special interest among these exhibits were the products of electrochemistry. To indicate the great importance of this branch of the art, we will quote from a recent address by Mr. F. J. Tone, President of the American Electrochemical Society:

"America has long enjoyed a supremacy in electrochemistry, but in spite of the strong position of the industry before the war no one would have dared to predict the expansion which the war would demand of us. It has called for chlorine, cyanamide, air nitrates, and phosphorus in vast quantities. It has required the ferro-alloy industry, the electrode industry, and the abrasive industry to quadruple their outputs.

"As a single example, consider briefly the contribution of electrochemistry and electrometallurgy to the aircraft program. The airplane motor has a crank case and pistons of aluminum. Its crank shaft and engine parts subject to the greatest strains are all composed of chrome alloy steel. All of these parts are brought to mechanical perfection and made interchangeable by being finished to a fraction of a thousandth of an inch by means of the modern grinding wheel made from electric furnace abrasives. Calcium carbide and its derivative, acetylene, are making possible an ample supply of cellulose acetate for airplane dope. When the aviator trains his machine gun on an enemy plane, his firing is made effective by tracer bullets of magnesium or phosphorus. When our bombing planes begin to carry the war into Germany it will be with bombs perhaps of ammonium nitrate or picric acid or other high explosives, all depending largely in their manufacture on electrochemical reagents. Without the pioneer work of Hall, Acheson, Willson, Bradley, and others, the present aircraft program would be impossible of achievement.

"Then there is gas warfare, the very basis of which is chlorine. Germany has long been a nation of chemists, and when she planned a war of frightfulness it followed as a matter of course that she should seek to make it also a war of chemical frightfulness. Much as we deplore it, therefore, we have been forced to throw our best energies to the solution of the problems of gas warfare. It is interesting to note that chlorine, the product of the electrolytic cell, is the basis of mustard gas, chlorpicrin, phosgene, and almost all of the important war gases. Thus does electrochemistry enter fundamentally into the modern military machine."

These are the war demands on electrochemistry—exceedingly urgent and altogether vital just now. However, they are no more important than the duties and problems that will devolve upon chemistry when the war is won. The science of chemistry is a leading factor in promoting better living conditions and the economic utilization of our resources; and it is with extreme gratification that electrical engineers observe the extent to which electricity serves the chemical industry and is interwoven with it.

In view of the prominence of electrochemistry the group of articles on the subject in this issue should be of special interest.

* * *

BETTER FREQUENCY REGULATION

The article by Mr. H. E. Warren in this issue of the Review on the subject "Better Frequency Control" is both interesting and significant. It is of great interest since it offers a more convenient and accurate method of maintaining constant frequency than old practices provide, while incidentally opening up a variety of novel and important uses for electricity in the way of electric timing devices both in connection with central station operation and for the vast number of consumers of electric energy as well. It is significant in that it marks a distinct step towards universal and standardized frequency which must come if we are to realize the predicted network of interconnected service lines extending all over the country, and tying together a multiplicity of large generating stations, each located at some particularly advantageous point as to market or water power, fuel, labor, condensing water, etc., in order that electric energy may be produced at minimum cost.

The criticism may be made that the Warren master clock is really a cycle recorder and not necessarily an indicator of constant frequency. This is perfectly true, but the fact remains that a reasonably careful observation of the relative change of positions of the two dial hands of the instrument enables the operator to maintain practically constant frequency more accurately and easily than can even be approximated in any other way.

Furthermore, this system establishes a brand new field for automatic electrical devices where spring wound clock mechanisms have woefully failed, making it possible to operate continuously, without necessity of winding and with great accuracy, all kinds of timing devices such as ordinary house and office "tickless" clocks, time switches, time stamps, time locks, program indicators, recording instruments, maximum demand devices, etc.

A number of large central stations have already synchronized their frequency with standard time by means of the Warrer master clock, with such satisfactory results that it would probably be difficult if not impossible to persuade them to return to their old methods.

It is to be hoped that an increasing number of stations will see fit to promptly adopt this system, thus securing for the industrial plants they serve the advantages of unvarying motor speeds and consequent maximum output so desirable under present war conditions.

Electricity Releases Chemistry's Power

By James M. Matthews

General Electric Company

Germany, looking forward to "Der Tag," included in its military program the establishment of itself as the foremost nation in chemistry. To attain this end it subsidized its chemical industries which could produce explosives as a by-product; and, operating on this basis, maintained its chemical supremacy by selling chemicals to other nations at so low a price as to make the business unattractive to domestic manufacturers. At the outbreak of the war imports from Germany were shut off and the nations were unpreparedly thrown upon their own resources. This condition, and our entry into the war, has resulted in our chemical industry growing as if by magic, and it is now our fourth largest enterprise. In this expansion, electricity has played the part of the ever-present servant, and in the maintenance of the industry on its new gigantic scale, electricity will be indispensable.—Editor.

Almost overnight America became a maratime nation; the foremost mining nation; the greatest steel producer; and the world's market basket. Now she has proved herself the world's master of chemistry and "back of it all is electricity."

How America Obtains Nitrates for Explosives and Fertilizers

America has awakened to a new day of activity. She has broken the subtle bonds of dependence upon a hostile people for essential substances. She has turned to her own vast stores of materials; and, with chemistry aided by electricity, she has found the way to make them serve her every need.

Our enemies, in the course of their long preparation for war, had stored large quantities of Chile saltpeter, the substance the world depended upon for nitrogen and explosives. The supply was largely in the hands of Germans and in the early days of the war it was protected by a German fleet. Furthermore, Chile was so far away that the Allies could ill spare ships to go for its saltpeter.

According to F. A. Clawson, Economist and Statistician of the National City Bank of New York City: "In the five years preceding the war, Germany had imported an average of 700,000 tons of nitrate of soda from Chile; France about 350,000; Belgium for herself and neighbors about 350,000; Great Britain 150,000; the remainder of Europe about 300,000 tons; and the United States about 500,000 tons."

While some of this imported nitrate was used for the production of explosives, especially by Germany, and also limited quantities were utilized for the production of nitric acid for chemical industries, a very large portion was used as plant food.

Chile, in supplying practically all the world's demand for niter, exported in recent years an average of about 2,100,000 tons per annum; and the importations of Europe and the United States aggregated about 2,050,000 tons per annum in the five years preceding the war.

Nitric acid for explosives, for the manufacture of sulphuric acid and other industrial uses, and nitrogen for fertilizers are made from Chile nitrate which, with sulphuric acid, is heated in retorts holding thousands of pounds and having electric motor-driven feed devices. The nitric oxide gas given off flows to condensers and absorption towers where strong nitric acid is formed. Electric motor-driven pumps supply the necessary water.

Last year, from the 1,713,000 tons of Chile saltpeter imported, 273,000 tons of nitrogen were obtained, which is more than that obtained from all other sources combined. This supply helps to meet the United States government demand for 180,000 tons of nitric acid per annum for explosives and the further demands which it is estimated will bring about the conversion of 1,000,000 tons of saltpeter to nitric acid this year.

A million and a half pounds of Chile saltpeter per day will be used in one of the government smokeless powder plants now being built at Nashville. This plant is to be seventy times as large as the largest smokeless powder plant in the United States before the war, and it is to be the last word in powder making. For its operation there will be required 1,500 tons or 100 carloads of coal a day and also 100,000,000 gallons of water, the latter quantity being sufficient to supply a city of a million people. The central power plant will contain 68 boilers each with a rating of 825 horse power. Electric motor drive will be used throughout.

Before the war, the fixation of atmospheric nitrogen had been carried on in Germany on a large scale by methods which had been kept secret by camouflaging their descriptions in the patents taken out in other countries.

In this way, Germany stored still more nitrogen for explosives. American chemists and electrical engineers have rediscovered these secrets and are now making nitrogen by those processes, greatly improved by American genius, as well as by the other processes used before the war.

The two processes most used for nitrogen fixation are the arc and the cyanamide. The former has mainly been used in Norway where about 350,000 electrical horse power are employed for this purpose. The arc furnaces in Norway are of two types known as the Schoenherr and the Birkeland-Eyde. The capacity of the former is 10,000 kw. while the latter are now being built in 4000-kw. sizes which are exclusively used in the new installations.

In the arc process, nitric acid is made by passing air through the electric arc furnace. The hot nitric oxide gases, obtained from the furnace, are first passed through a boiler which serves the double purpose of cooling the gas as well as generating steam which can be used for concentrating and evaporating purposes as well as for power regeneration. About 1.5 per cent of the gas is changed to nitrogen peroxide. This is absorbed by water in absorbtion towers to make a liquor containing weak nitric acid. In two towers the gases are absorbed by soda ash to make sodium nitrate. Some of the nitric acid is sprayed onto calcium carbonate (lime) to produce calcium nitrate for use as a fertilizer and for aniline dye manufacture. This Norwegian saltpeter, solidified by cooling, is put through ball crushing mills for reduction to a granular state. Nitric acid liquor is also brought into contact with ammonia liquor from gas works to produce ammonium nitrate, an important explosive.

In the cyanamide method for the fixation of atmospheric nitrogen, red hot calcium carbide is used to absorb nitrogen that is obtained by fractional distillation from liquid air. The product, calcium cyanamide, a highly efficient fertilizer, is steamed to produce ammonia, and this is oxidized to produce nitric acid. Electricity is used throughout this process for power, heat, and light.

The calcium carbide used in this process is itself an electrochemical product and is produced in the cyanamide industry. The raw materials entering into its composition are lime and coke or anthracite. The lime is obtained by burning limestone in kilns having electric motor-driven blowers and then it is crushed in electrically driven mills. The lumps are then mixed with the coke or anthracite, also crushed electrically, and the mixture is melted in electric furnaces at an estimated temperature of 2200 deg. C. (4000 deg. F.) to produce calcium carbide. The power input to these furnaces is automatically held constant by an automatic control consisting of a contact-making ammeter which actuates motors to raise or lower the furnace electrodes.

The calcium carbide is then crushed, finely ground, packed into pots and placed in an electrically heated furnace that brings it to a red heat ready to absorb the nitrogen gas made in the following interesting manner:

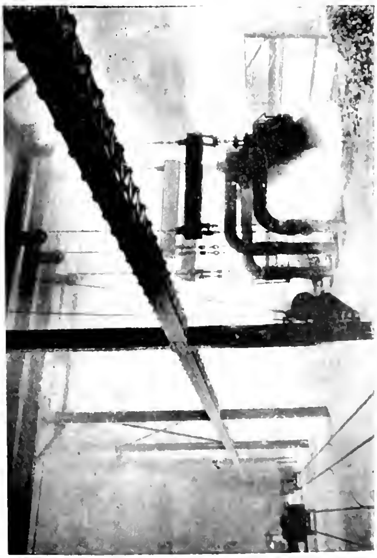
Air is first liquefied, producing a temperature of −190 deg. C. (−312 deg. F.) which is about the lowest temperature used in a commercial process. The machinery is electric motor-driven.

The liquid air, absorbing heat from its surroundings, boils and gives off nitrogen which is piped to engines. Its expansion in these engines drives electric generators loaded on resistances which can be varied to give the precision of power control essential to the successful fractional distillation of liquid air.

After the expanded nitrogen is absorbed by the hot calcium carbide to produce cyanamide, the mass is crushed, finely ground, and hydrated by water from electric pumps to rid it of carbide.

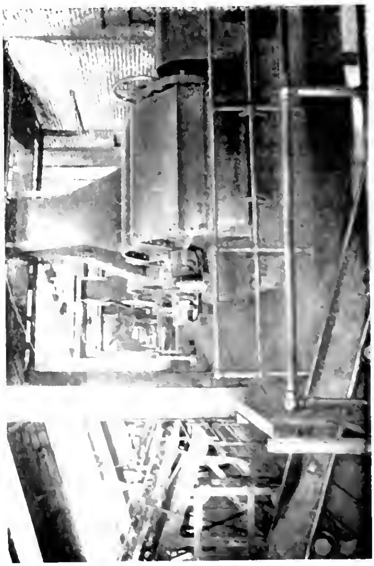
The cyanamide is treated with steam in autoclaves, driven electrically, to produce ammonia which is mixed with air and passed through an electrically heated platinum-screen catalyzer to produce nitric oxide gases. These, oxidized and absorbed by water in towers, produce nitric acid.

The United States government will have in operation within a month, November 1, 1918, a cyanamide process plant at Muscle Shoals, Alabama, capable of producing 110,000 tons per annum of the shell bursting explosive ammonium nitrate, which is made from ammonia and nitric acid. Other government plants at Cincinnati and Toledo will each produce half this quantity. A 30,000-ton ammonium nitrate factory has been completed at Sheffield, Alabama. The nitrogen in this plant is produced in the form of ammonia by the General Chemical Company's synthetic ammonia process which is a modification of the German Haber process. A similar plant for the production of nitric acid is contemplated by the Navy Ordnance Department and is to be located at Indian Head, Md.

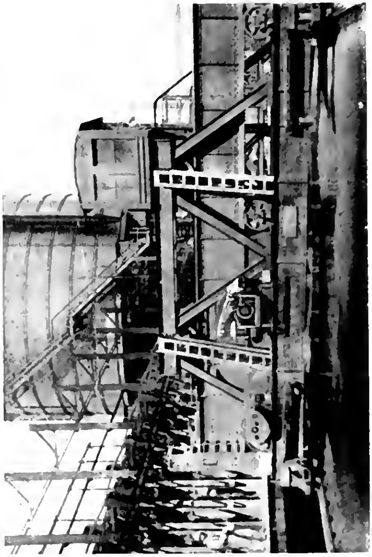


Electric Calcium Carbide Furnace in Cyanamide Plant

Obtaining Nitrogen by Fractional Distillation of Liquid Air



Hammer Mills Driven by 250 h.p. Induction Motors Through a Wall. These mills reduce coal to dust for charging into coke ovens which produce raw materials for dye manufacture

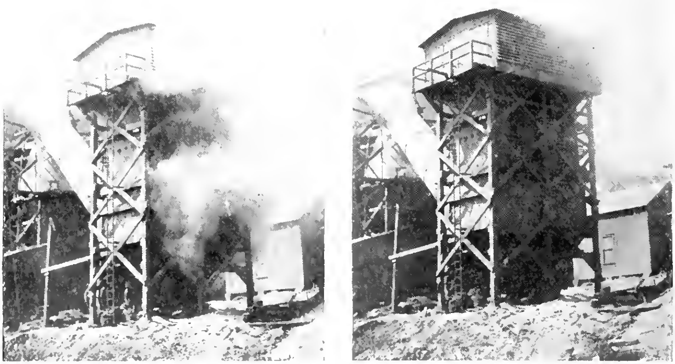


Motor operated Traveling Coke Pusher at Indiana Steel Company, Gary, Ind., which discharges coke from ovens into a quenching car

The production of nitric acid in the United States next spring will be nine times normal, as it is expected 650,000 tons will be made from sodium nitrate and 225,000 tons by the oxidation of ammonia. As four fifths of this production is in excess of peace time consuming capacity, America will be more than independent for its nitrogen compounds, especially as she can make synthetic nitrates cheaper than she can buy Chile saltpeter.

As doubling the rate of fire reduces an army's losses by half, the importance of an adequate supply of nitric acid for explosives is readily seen.

Since two tons of ammunition are used up on the western front for each soldier killed, it is evident we must supply vast quantities of explosives to win the war. These explosives are all compounds made from nitric acid, or ammonia, or both, as TNT (tri-nitro-toluol) is made from toluol (distilled from coal) and nitric acid; picric acid is made from benzol (another coal derivative) and nitric acid; and ammonium nitrate is made from ammonia and nitric acid.



Current Off — Current On

Electrical Precipitation

Obtaining American Potash to Feed and Clothe the Allies

Our allied warring nations can be fed only from the increased yield of America's fields. Before the war, the only developed source of potash, so vital as a plant food, was in the enemy's hands at Stassfurt, Prussia.

American chemists and electrical engineers have shown the way to the potash in our lakes, slates, rocks, and sea weed; and also how it can be precipitated electrically from the dust-laden waste gases of cement mills and blast furnaces.

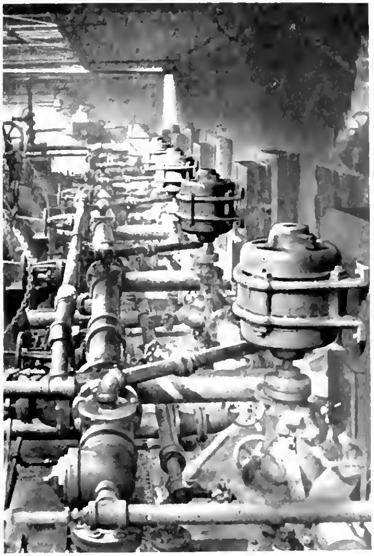
According to the United States Geological Survey, the production of potash for the first half of this year was between 20,000 and 25,000 tons, and it is estimated that the total for the year will reach 60,000 tons which is about 25 per cent of our pre-war importations.

Our production of potash has doubled during the last year without any real assistance from electrical precipitation at blast furnaces in this country. The latter could produce enough potash to more than equal our pre-war importations, according to the calculations of Mr. Wysor, based on his experience with electrical precipitation at the Bethlehem Steel Company's plant and his knowledge of the Cambrian iron ores of Alabama.

The briny waters of Searles Lake, California, are being made to produce potash at the rate of 54,000 tons per year according to an article* by Alfred de Ropp, Jr., Research Engineer of the American Trona Corporation.

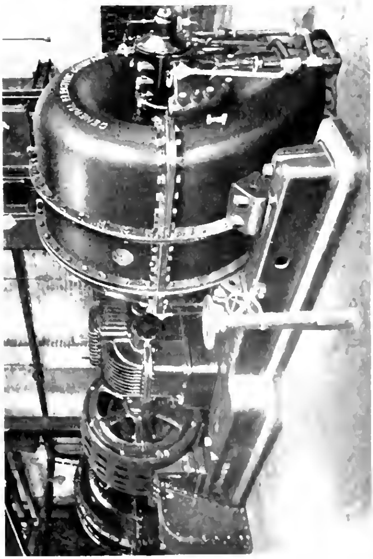
The cement mills of this country are capable of producing from 100,000 to 220,000 tons of potash per year, according to Mr. John J. Porter, Vice President and General Manager

* *Metallurgical and Chemical Engineering*, vol. xix, No. 6c



Electric Motor driven Pumps in By-product Recovery Plant of Semet Solvay Co., Detroit, Mich., Which Produces Raw Material for Dye Manufacture

40 h.p. Motor Driving Dye Mixer at National Aniline & Chem. Company, Buffalo, N. Y.



[illegible] G. E. B[illegible] M. Kinney Steel Company, Cleveland, Ohio [illegible] by-product plant

[illegible] h.p. Motor Driving Stirrer in Dye Mixing Vat at National Aniline & Chemical Co., Buffalo, N. Y.

of the Security Cement and Lime Company at Security, Maryland, which has recovered potash by electrical precipitation since June, 1916. This cement plant is but one of six employing electrical precipitation.

About 10,000 tons of potash per year are obtained in this country from kelp, or seaweed, on the Pacific coast. Alunite, molasses residue, wood ashes, evaporated water from sugar refineries, evaporated water from wool washings and insoluble industrial waste were the sources from which last year there were produced 6336 tons of potash. The rocks and slates of Georgia, the green sands of New Jersey, and the leucite deposits of Wyoming all offer other opportunities to increase our potash production.

The processes used to recover potash are interesting enough to warrant a brief description in view of the great expansion being made in this industry at the present time.

At Searles Lake the brine is pumped from wells in the lake salt deposit to storage tanks and vacuum pans. From these it is sent to multiple-effect evaporators and then to crystallizing vats for eight days, after which the liquor is drained off leaving crude potash salts which are carried to drain floors by electric hoists. Electrically driven mills grind the potash before shipment. Electric power for the various other drives has been installed to effect a considerable saving in oil which had been burned for fuel under boilers having a total capacity of 12,500 h.p.

The recovery of potash from the waste gases of cement kilns in some cases is bringing in greater profit as a by-product than is being realized from the cement manufactured.

At Security, Maryland, the waste gas from cement kilns is passed through a stack containing 800 sections of pipe, 16 feet long by 12 inches in diameter. Passing lengthwise through the center of each pipe there is a wire which is insulated from the pipe. A unidirectional potential difference of from 60,000 to 70,000 volts is maintained between the wire and pipe. This high voltage produces a corona discharge from the wire. The particles of gas-borne dust passing by are given an electric charge and are driven against the inner wall of the pipe. Rapping the pipes at intervals with a system of hammers causes the dust to fall from their walls into hoppers beneath them. By adding salt to the mixture used for making cement, as well as to the coal used for fuel, and by flowing water over the inner walls of the pipe, a larger percentage of potash is recovered on evaporating the water. With this process in use, the coal required for making cement has been reduced from 96½ to 87 pounds per barrel.

To get the high-potential unidirectional current needed for electrical precipitation, if low-tension alternating current is available, there is required a transformer to step up the voltage to that required for the precipitator and a rectifier or air break switch for changing this to a unidirectional current. The rectifier is usually driven by a 2- or 3-h.p. synchronous motor. If only direct current is available, a small motor-generator set or synchronous converter is needed to produce the low-tension alternating current and can be made to drive the rectifying switch. This apparatus is all of small size, as a precipitator to handle 10,000 cu. ft. of gas per minute will usually require only 7 to 10 kilowatts.

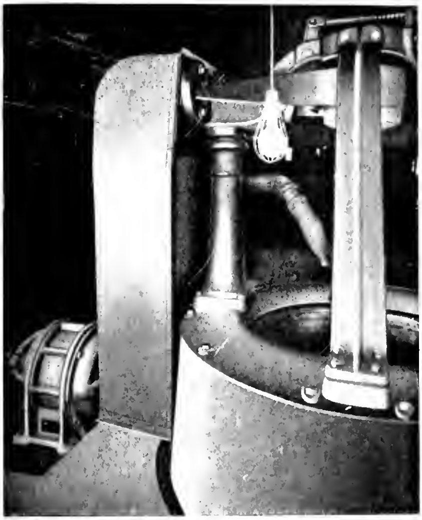
Potash and other valuable chemicals are made from kelp or seaweed on the Pacific coast. This seaweed is cut by power-driven harvesting devices on sea-going ships. It is pulled out of the water by power-driven conveyors, placed on lighters, and carried to land. Here it is dried and sold to fertilizer companies, or fermented with the addition of finely ground limestone for 15 to 20 days to bring the potash into solution and to produce acetic acid. At the end of the fermentation period, the resultant liquor is pumped from the fermentation tanks, sterilized, and filtered. It is then ready for the evaporating and crystallizing operations where a partial separation is made of the potash produced in fermentation.

These salts are put through acetone retorts for the manufacture of acetone, potash, iodine, and a product resembling methyl ethyl ketone, which is employed entirely in the production of smokeless powder. The high degree of purity of the chemicals obtained from kelp recommends this process of potash recovery where such purity is desired.

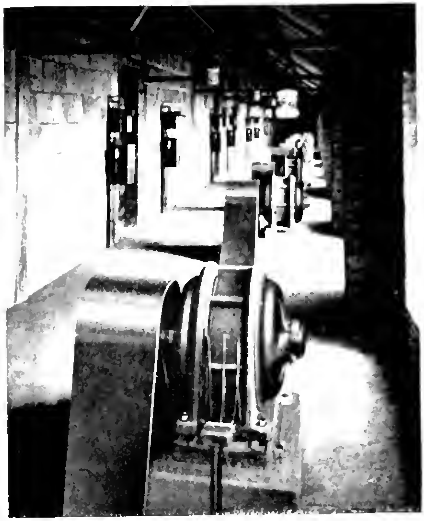
From the potash-bearing seracites of Georgia, a large percentage of potash can be recovered by volatilizing it and precipitating it electrically.

Dyes and Chemicals now Made in America Electrically

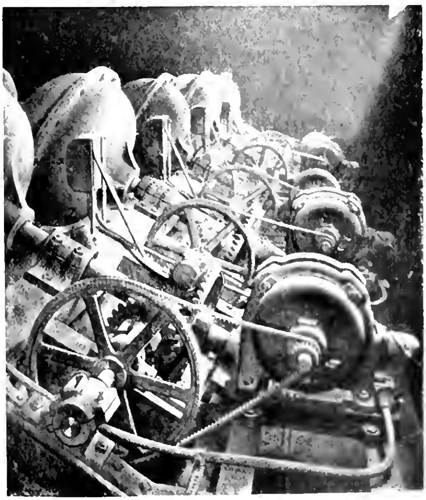
Before the war, we Americans were mixers of dyes rather than manufacturers, as fully 90 per cent of our artificial dyes and colors, which had displaced natural dyes, were imported. But one concern manufactured



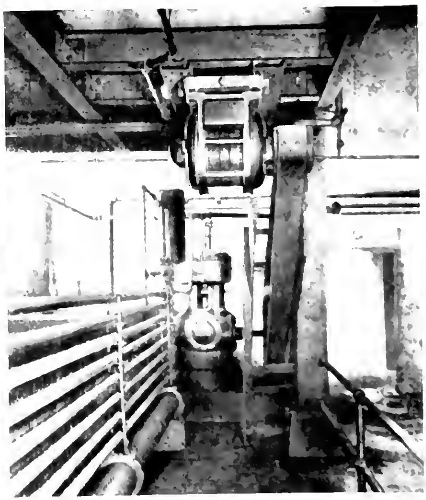
5-h.p. Motor Driving Centrifuge at National Aniline & Chemical Co., Buffalo, N. Y.



10-h.p. Motors Driving Dye Reducers — Benzol Products Co., Marcus Hook, Pa.



2-h.p. Motors Driving Ball Mills at National Aniline & Chemical Co., Buffalo, N. Y.



25-h.p. Motor Driving Refrigerating Machine to Keep Down Reaction Temperatures at National Aniline & Chemical Company, Buffalo, N. Y.

aniline, the source of many dyes, and the value of our annual exports of dyes, dyestuffs, and dyewoods was only $357,000 as compared with $17,000,000 today.

Our chemists have not only made America the largest producer of *natural* dyestuffs in the world but have discovered upwards of two hundred *artificial* dyes which meet America's needs for acid, basic, chrome, and direct dyes.

The alizarine group of dyes, for turkey red cottons, and artificial indigo, have recently become available after months of intensive research work.

All these artificial dyes are equal in quality and fastness to the same dyes which were formerly imported, and their development has been accomplished under the handicap that the United States government demands for other purposes quantities of many of the raw materials needed for dye manufacture. The introduction of such colors as sapphire, the fastest blue known, both for wool and silk, shows the trend in American dye making. Sample skeins of yarn dyed with this color and exposed for seven days to the action of the sun reveal no effect of the rays.

It was to the young American dye plants that the United States turned to find the necessary skill and experience to produce poison gas. This has been so successfully done that Germany, the originator of poison gas warfare, will get an overwhelming amount of it.

Coal tar, the source of many artificial dyes, and many important medicines, which in quantity and quality have fully met the needs of our army, represents a link in a chain of products whose manufacture is highly interesting.

Coal is drilled, cut, hauled, hoisted, conveyed, and crushed in electrically lighted and pumped mines. Most of the power used is supplied by electric motors which are specially designed to withstand the working conditions met in mines. The coal is unloaded electrically by great movable bridges with projecting arms at the end of which are grab buckets of many tons capacity. These buckets are lowered into ships or railroad cars, then they hoist the coal, and dump it into hoppers or transfer cars. Electric motor-driven conveyors carry the coal to breakers and hammer mills which reduce it to a powder.

The crushed coal is conveyed by other electrically driven conveyors to a mixer building where different varieties of powdered coal are mixed to give a maximum yield of coke. All the crushing, conveying, and mixing machinery is *interlocked electrically* so the stopping of any conveyor or machine automatically holds up all operations prior to its own, thereby preventing waste or jamming.

Electric larry cars on top of coke ovens carry charges of definite weight to charging holes over each coke oven, and electrically operated levellers even up the charge.

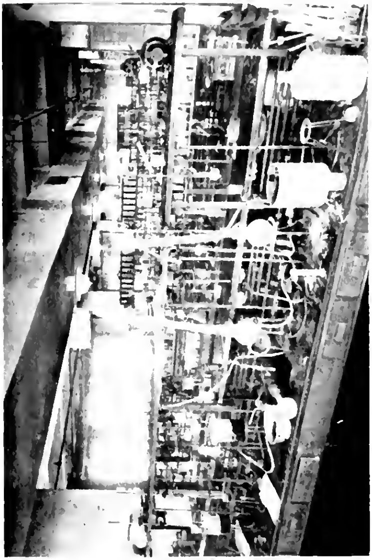
The air for a common type of coke oven is drawn through hot brickwork into heating flues in one of the oven walls, then mixed with gas from the by-product plant, and burned to heat the coke ovens. The combustion gases from the ovens heat up a reserve brickwork which is used to heat the air when the first brickwork has cooled off. The reversal of draft which makes the use of this regenerative principle possible is automatically accomplished by clockwork which operates electric motor-driven valves.

After the coking process has continued for 18 hours, the oven door is opened by a traveling electric door opener and the red hot coke is pushed out onto cars by an electrically operated coke pusher which can be moved to any oven as needed. This coke is quenched by water from electric motor-driven pumps and pulled by electric locomotives to motor-operated crushers and screens.

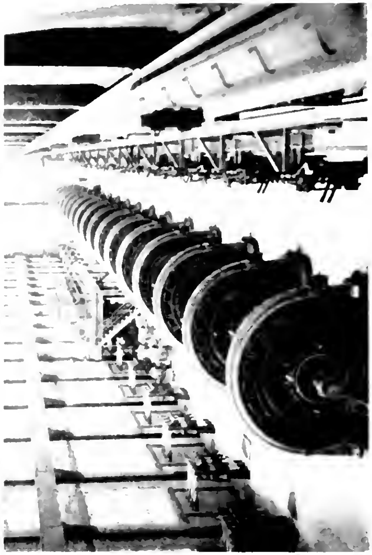
The gases from the ovens are drawn by a centrifugal gas booster through mains in which coal tar settles out, then to coolers and tar extractors.

The gases are then treated to produce concentrated ammonia liquor for nitric acid manufacture or fertilizer manufacture, or are treated with sulphuric acid to produce sal ammoniac. After this cleansing, the gases are burned to produce power in the steel plant which is usually adjacent to a by-product coke plant.

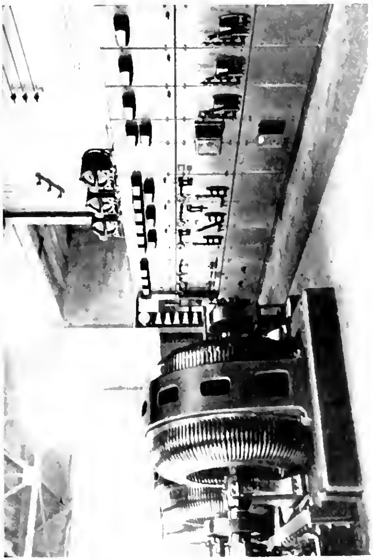
The coal tar is separated into colorless constituents such as benzol, toluol, etc. These materials are received by the dye manufacturer in a pure condition and are subjected in kettles and vats, having electric motor-driven stirrers, to the action of nitric acid to make aniline, a clear liquid. Further treatment in vats or kettles by nitric acid, in the presence of sulphuric acid as a catalyzer, followed by reduction with fused caustic soda or oxidation with air or nitric acid, produces finished dyes in electric motor-driven kettles, vats, mixers, centrifugals, grinding, and ball mills. Electric motor-driven refrigerating machines are employed



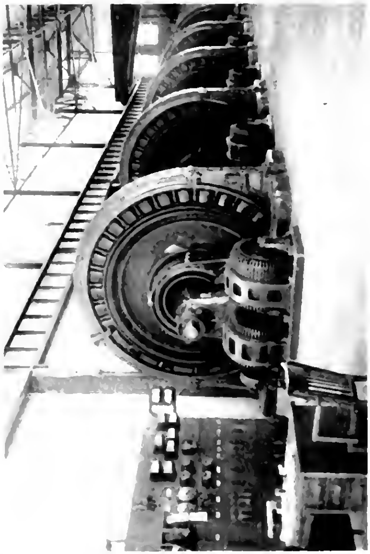
1/4-h.p. Motor Operating a Series of Stirrers in Chemical Laboratory at National Aniline & Chemical Company, Buffalo, N. Y.



Eighteen 2500 kw. Synchronous Converters, Aluminum Company of America, Massena, N. Y.



[illegible] Controlling Three 750 kw., 2200 volt Kerr Turbines at National Aniline & Chemical Company, Buffalo, N. Y.



Five 1800 kw. Synchronous Converters at Anaconda Copper Mining Company, Great Falls, Mont.

to prevent the solutions from becoming too hot while undergoing chemical reactions.

Electrochemical Products are Indispensable to Winning the War

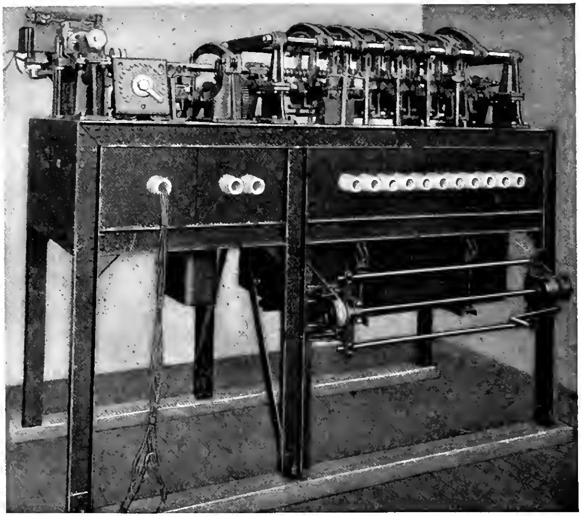
The electrochemical industry will soon be the largest single user of electric power. Its products play a vitally necessary part in the conduct of the war, as is shown by the following brief description of their manufacture and uses.

Aluminum requires the maximum amount of power per pound of any of the electrochemical products. It is made from bauxite, which is melted down and purified in an electric furnace and then in an electrolytic cell, with cryolite and fluorspar, it is subjected to a direct current of electricity which keeps the mass molten and collects the aluminum at the lower electrode ready to be tapped off at intervals. Certain alloys of aluminum and magnesium for airplane construction are exceedingly strong and are lighter than aluminum. These alloys are also used in making star shells to illuminate the battlefields at night.

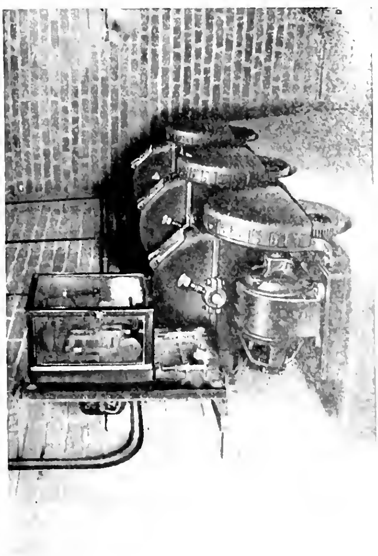
Power is supplied for the manufacture of aluminum by synchronous converters having a voltage regulation varying from 33 to about 10 per cent, figured on the maximum voltage required. This range is necessary because of the difference between the starting and the running voltage of the cells. Variation in the voltage per cell is required by the differences in temperature and density of the solutions, and a variation is also required to compensate for the number of cells in series.

The regulation of voltage is obtained by split-pole converters, induction regulators, or boosters in the alternating-current circuit, or, in some cases, by regulation of the alternating-current voltage at the generating stations. The service requirements are generally severe on account of the imperative continuity of operation, so the machines should have a greater margin in capacity than those designed for a more ordinary service. The conditions as regards commutation and stability are favorable on account of their steady nature.

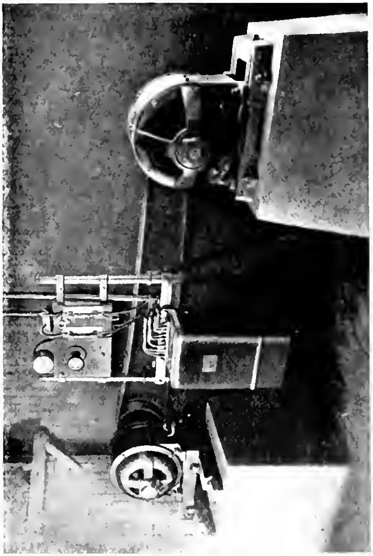
The manufacture of artificial abrasives comes next to aluminum as a power consumer. Artificial abrasives are made in electric furnaces of either the arc type,



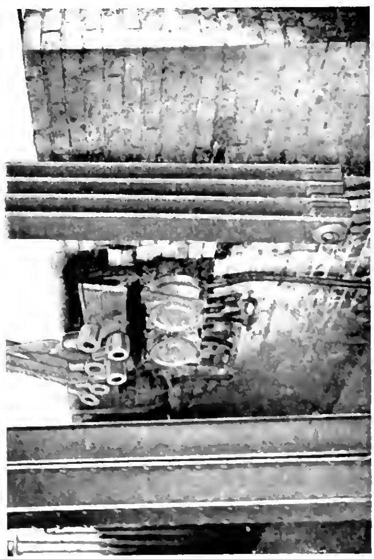
Motor-operated Multiple Pole Oil Switch for Controlling Power Supplied to Carborundum, Graphite, and Other Electric Furnaces



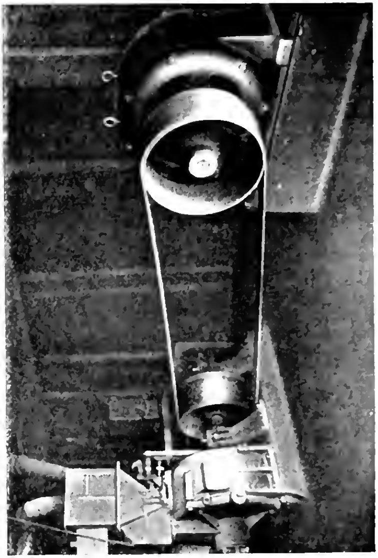
h.p. G.E. Motor Driving Electrode Winches to Raise and Lower Furnace
Cables at General Abrasive Company at Niagara Falls, N. Y.



Motor driven Generator for Supplying Direct Current to Electrode Winch
Motors at General Abrasives Company, Niagara Falls, N. Y.



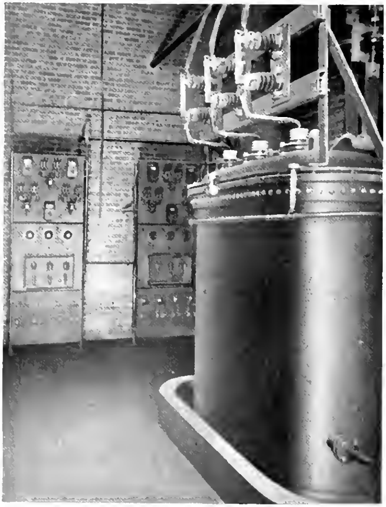
End of Carborundum Furnace. Carborundum Company of
America, Niagara Falls, N. Y.



50 h.p. Motor Driving Coke Crusher. Carborundum
Company of America

having movable electrodes, or in resistance furnaces.

The electric furnace for making carborundum consists of two brick walls set many feet apart. Through the center of each wall a water-cooled carbon or graphite electrode passes and projects a few inches. These electrodes are joined by a trench filled with a mixture of sawdust, sand, coke, and salt, covered over with sand. By utilizing a large amount of electric energy, the central portion of the furnace is brought to about 2200 deg. C., at which temperature the silica (sand) is volatilized. One molecule of silicon combines with one of carbon forming silicon carbide. On cooling, a core of pure crystallized carborundum is found surrounded by fire sand which is itself highly refractory. The current in these furnaces is supplied by transformers having many taps, the connections of which are automatically shifted to keep the power input at the desired value.

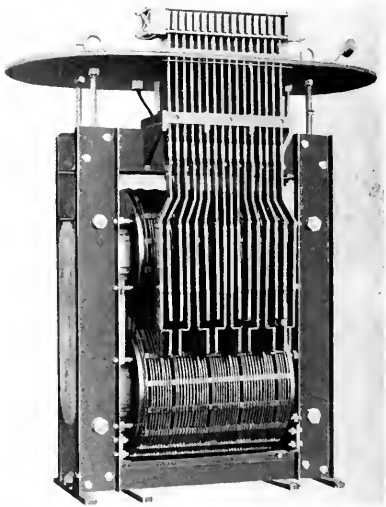


11,000 to 80-volt, 3500-amp. Transformer Supplying Power to Electric Abrasive Furnace, and Automatic Ammeter Control Switchboard in Background. General Abrasive Co., Niagara Falls, N. Y.

The carborundum core is broken up, the crystals sorted and screened, and wheels, stones, etc., shaped with suitable cementing material—all the power being supplied by electric motors.

Other abrasives, resembling but more uniform than emery, are mainly compounds of bauxite and are made in electric arc furnaces. These furnaces are tapped at intervals by an arc from an auxiliary electrode which burns a hole through the side into the bath.

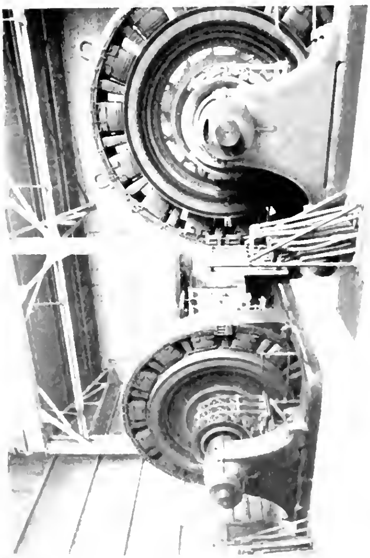
The power input of these furnaces is kept constant by direct-current motors which raise or lower the electrodes. These motors are controlled by a contact-making ammeter, the direct current for them being supplied by a motor generator set. With this method of control, charts taken over a twenty-four-hour period show practically a straight line for power input.



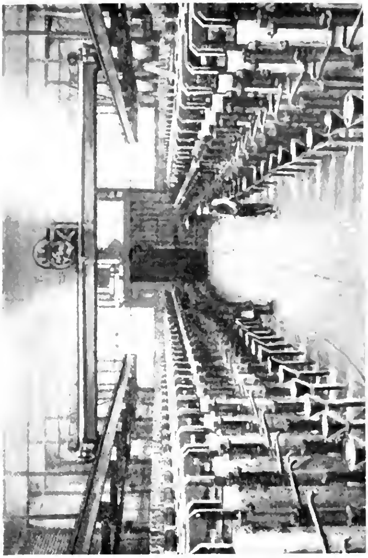
Transformer with Cover Removed. This Transformer is especially arranged for supplying power to electric furnaces

Not a shell is made that is not shaped by electrically made abrasives. Without the latest grinding devices made of artificial abrasives, a factory producing 500 auto trucks or airplane engines a day would have its output reduced to 100 or would have to shut down, as all emery came from Turkey and the supply may never be renewed.

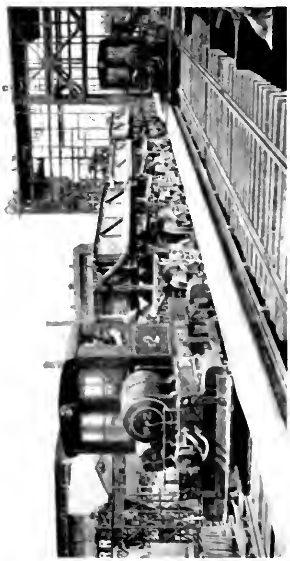
Ferro-alloys require the next largest amount of electric power in their manufacture.



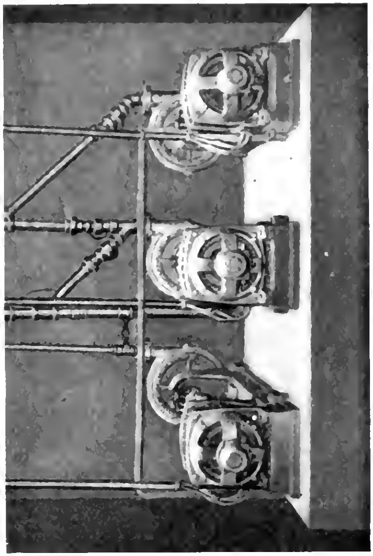
Two 1,140 kw Synchronous Converters at Hooker Electro-chemical Company, Niagara Falls, N. Y., supplying Current for Chlorine and Caustic Soda Manufacture



Chlorine and Caustic Electrolytic Cells. Hooker Electrochemical Company, Niagara Falls, N. Y.



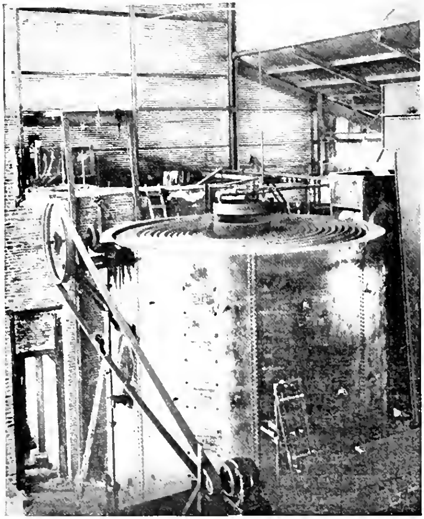
Electric Locomotive Hauling Pyrites at Sulphuric Acid Plant of Davidson Chemical Company, Baltimore, Md.



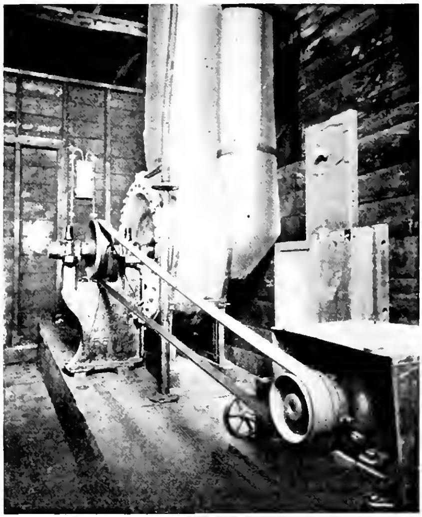
Electric Pumps Cooling Rakes of Sulphur Burners at a New England Chemical Company

They are vitally necessary to winning the war as by them molten steel is scavenged or cleaned of dissolved oxygen to avoid the production of blow-holes in castings. They also impart to the steel the desired degree of toughness, hardness, strength, or heat resistance.

The noses of shells, mining and grinding machinery, etc., require a tough hard steel which can be made by adding 12 to 14 per cent of manganese in the form of ferromanganese. Very small quantities of this alloy are also used in making low carbon or soft steels.



Sulphur Burner with Electrically Driven Rakes in a Sulphuric Acid Plant



Lead-covered Sulphur Gas Fan Driven by Electric Motor, which has operated without stopping for the last five years at a New England Chemical Company

Ferromanganese is made in the electric arc furnace by melting manganese ore, carbon, silicon, and iron turnings. The power input for this type of furnace is easily kept perfectly constant by contact-making ammeter control of electric motor-operated electrode winches.

Ferrochromium gives us our hardest steel for armor plate, soldier's helmets, armor-piercing projectiles, high-speed steel, steel for auto trucks, ball bearings, jaws and linings of crushing machinery, and die steel; and, in conjunction with other alloys, it is also used in practically every kind of alloy steel.

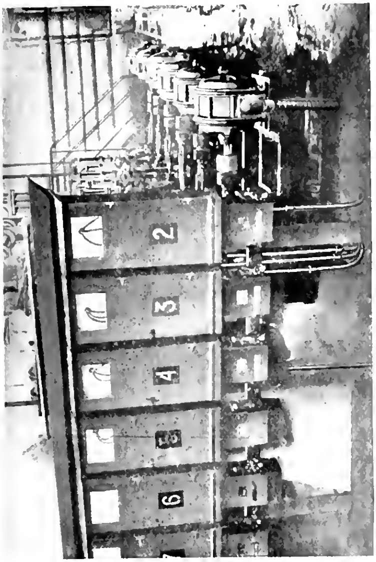
Ferrochromium is made from chromite and carbon in the electric furnace. It is remelted to oxidize out the excess of carbon above the steel makers' requirements.

Ferrovanadium, which is used in steel for airplane and automobile engine shafts or wherever unusual strength is required to withstand the heaviest shocks and vibrations, is made in an arc furnace into which are put the oxides of vanadium, powdered silicon, iron, lime, and fluorspar.

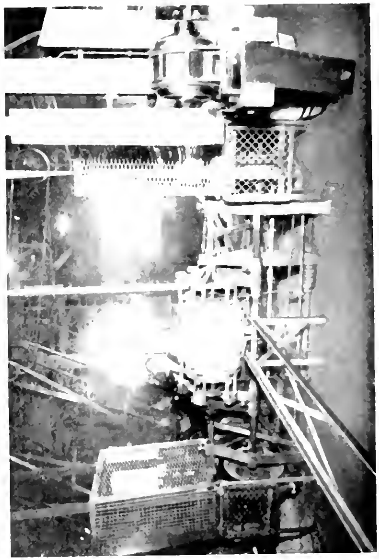
Ferrotitanium is largely used in the steel rail industry to insure sound ingots by removing oxygen and nitrogen from the molten steel. Titanic iron ore and carbon when melted in the electric furnace produce ferrotitanium.

Ferromolybdenum, that oxidizes only at a high temperature and is so hard it wears but little, is used with tungsten to produce a hard lining for gun barrels and many parts of guns, gun carriages, motors, automobiles, etc.

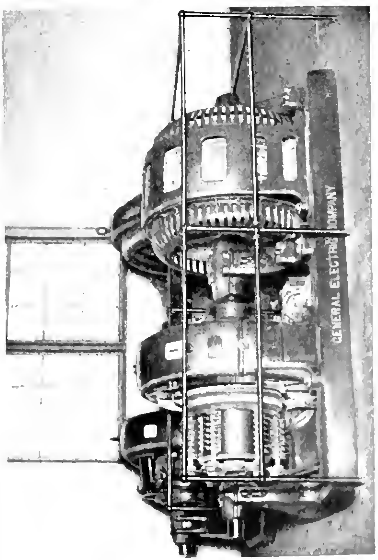
The oxide of molybdenum is reduced by carbon in an electric furnace in which there



10-h.p. Motors Driving Ammonia Pumps, Solvay Process Company, Syracuse, N. Y.



Motor-driven Barrel Hooping Machine at Solvay Process Company, Syracuse, N. Y.

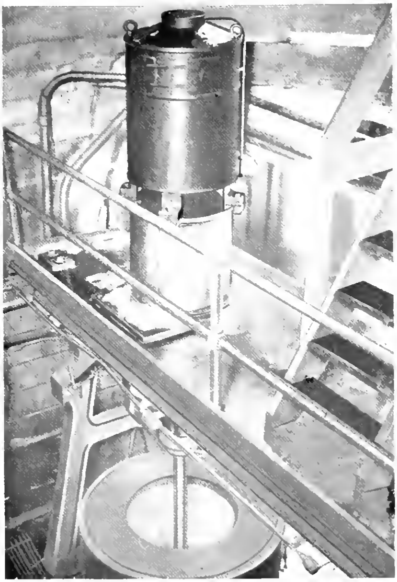


Synchronous Motor for Correcting Power-factor at Solvay Process Company, Syracuse, N. Y.

50-h.p. Motors Driving Blast Fans in Lime Kiln Solvay Process Company, Syracuse, N. Y.

is also some iron scrap and lime. Its quick, cooling property makes it necessary to take apart the furnace in order to get the alloy.

Ferrotungsten makes steel self-hardening by cooling in air without quenching; and, if used in large enough quantities, makes a tool steel that will stay hard when raised to a red heat by fast cutting. This high-speed tool steel



Motor-driven Centrifugal in Bicarbonate of Soda Department, Solvay Process Company, Syracuse, N. Y.

has greatly increased the capacity of the machine shops of the world; some authorities estimate the increase as three to five times the capacity obtained with ordinary carbon tool steel. It is also used for magnet and gun steel, as well as for machinery.

Ferrotungsten is made in an electric arc furnace from iron turnings and an oxide of tungsten. The latter occurs in our western states and is a valuable war asset.

High-grade ferrosilicon can be efficiently made only in the extreme temperature of the electric arc furnace from sand, coke dust, and iron or steel turnings or punchings. Specially insulated and tapped transformers and special electric motors are required for this type of furnace and the successful operation of the electrical equipment under the severe duty imposed is a great testimony to the efficiency of electric power equipment.

This alloy is used as a scavenger to quickly remove dissolved oxygen from molten steel, to reduce the possibility of blow-holes and thus produce sound castings. It is used in the manufacture of all steel made by the basic open-hearth process (20 per cent of our output) and is essential in practically all the commercial forms of steel. It is largely used in shell steel, cast-iron foundries, in the manufacture of silicon steel for electrical apparatus, and in almost all other processes of steel manufacture. It is used in the production of hydrogen for dirigible and observation balloons, etc.

Other ferro-alloys impart valuable properties to steel but their manufacture has not reached the large proportions attained by those described.

As the oxides from which the foregoing alloys are made are obtainable here and play such an important part in munition work in this country, they constitute a very important factor in winning the war.

The scarcity of matches in France has resulted in the use of lighters operating on the steel and flint principle. Thousands of these lighters made of steel and pyrophoric alloy are used in the trenches to light the "smokes."

Pyrophoric metal was invented by Welsbach, an Austrian, and was made of cerium, produced in Austria, and 30 per cent of iron and other metals, which were added in the countries where the alloy was to be used. After the war started, American chemists discovered how to make cerium by electrolysis, for incandescent gas mantles and for pyrophoric alloy. The alloy is largely used for igniting mechanical fuses, as in grenades, and pocket lighters, as well as for miner's lamps, gas lighters, etc.

Next to the ferro-alloys the production of sodium and potassium chlorates require the largest amount of electric power. These chlorates, which make our matches possible, are made in electrolytic cells from the chlorides of these metals.

The metal sodium, which forms in an electric furnace under molten caustic, is required in the manufacture of sodium peroxide, which in turn is used in the manufacture of hydrogen peroxide and a great quantity of the world's supply of chloroform.

Phosphorus manufacture comes next as a user of electric power. It is made in large quantities in electric furnaces and is used for hardening bronze, on safety match boxes, etc. It is used in large amounts by the army for smoke bombs and by the navy to create smoke screens as a protection against submarine attack.

The electric furnace which gives us our hardest materials also gives us soft graphite lubricants. Graphite is produced by first baking a mixture of ground coke, asphalt cement, etc., to drive out impurities and then graphitizing the mixture at a higher heat. This material is made into electrodes, lubricants, etc. A multi-tap transformer is used to permit change of voltage periodically, and the type of furnace used is similar to that in which carborundum is made.

While the chlorine industry comes last as an electric power user it is of vital importance in conducting the war, for it is from this source that we get poison gases, and also some of our caustic soda; many of the valuable uses of which will be described later.

To make caustic soda, brine is run into a series of electrolytic cells which separate it into caustic soda and chlorine gas. In these cells a vertical carbon or graphite electrode is surrounded by a large tube and the annular space between filled with brine. The tube is surrounded by another or cathode tube containing kerosene oil. These tubes are closed at the bottom and a diaphragm is used for part of the inner tube. When current is turned on, caustic liquor in bubbles rushes to a cavity at the bottom of the outer tube and is drawn off to multiple-effect vacuum pans or evaporators. Chlorine gas rises in the inner tube and is piped to liquefiers or chambers containing slacked lime to change the latter to bleaching powder.

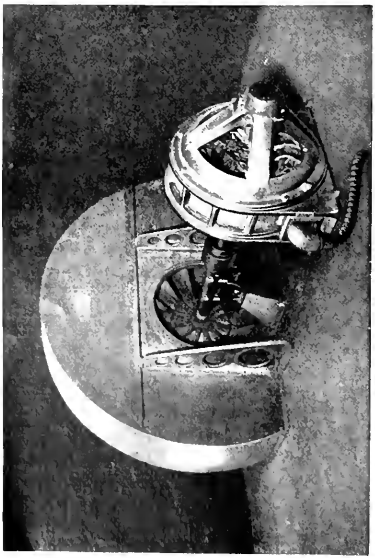
Chlorine gas, as made by the electro-chemical companies, is the basis of poison gases and its manufacture is being pushed with all speed. As soldiers are only 50 per cent efficient when wearing a mask, poison gases such as chlorine, phosgene, chlorpicrin, and mustard gas, are used in a variation to surprise the enemy and make him keep his mask on. Chlorine is also used in making cloud gas, smoke screens, disinfectants, sterilizers, explosives, picric acid, airplane waterproofing, chloroform, and the best preventive of blood poison from infected wounds.

Hydrogen, a by-product in the manufacture of hydrochloric acid, is used in the presence of a catalyzer for changing benzol into dye intermediates.

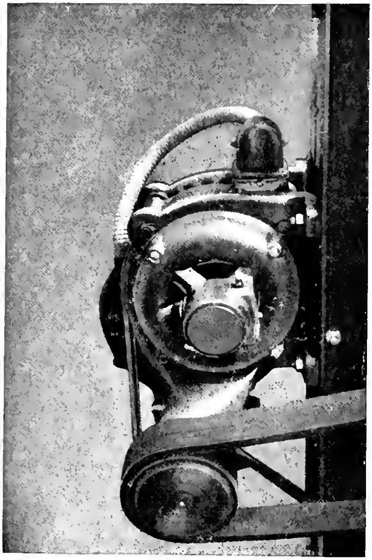
Calcium carbide is made in a furnace similar to that used for ferro-alloys and is utilized for generating acetylene gas for lighting mines, signal lamps, lighthouses, etc., and in the manufacture of alcohol, acetic acid

Motor-driven Beaters in a Paper Mill. Chemicals are usually added to color the pulp in the beaters

Motor-driven Paint Grinders and Mixers, American Seal Paint Company, Troy, N. Y.



75-h.p. Motor-driven Glass Furnace Blower. American Bottle Company, Streator, Ill.



5-h.p. Motor Driving Limed Juice Mixer. Garden City Sugar & Land Co., Kansas

Motor-driven Alum Vat Stirrers at a Large New England Chemical Company

Electrical Equipment for Dehydrating Oil and acetone. It is also used to produce fertilizer and ammonium nitrate by the cyanamide process previously described and may be the future source of most of our dyes. Acetone, together with asbestos, is used to absorb acetylene gas under pressure and prevent explosions in automobile gas tanks. Acetylene and oxygen are used for both welding and cutting metals.

The Production of Sulphuric Acid an Indicator of Military Activities

For many years we have heard that the consumption of sulphuric acid was an index of the degree of civilization, but today it has become an indicator of the intensity and magnitude of warfare.

In 1917 we made over 7,000,000 tons, nearly twice that of 1913, which may be taken as a normal pre-war year. This 1913 production was based on the use of Spanish pyrites by sulphuric acid plants. A change-over to domestic ores has been made, involving changes in manufacturing methods, but the industry is serving the allied warring nations with remarkable ability.

The many uses of sulphuric acid are too long to list here but their importance can be judged by the fact that the explosive, fertilizer, dye, and alcohol industries all use sulphuric acid.

In making sulphuric acid, the pyrites are unloaded by electric motor operated conveyors and passed through crushers driven electrically. These pyrites are roasted in furnaces consisting of a vertical metal cylinder lined with a refractory substance and having a row of screen shelves around its inner surface. Between these shelves there is a series of water- or air-cooled rakes which are rotated by electric motors. Pyrites, placed on the upper screen shelf, are raked through the screen by the revolving rakes onto the next shelf, where the process is repeated. After the pyrites start to burn in this furnace, they supply enough heat to continue the operation as long as their supply is kept up. Electric power is used to drive the rakes and the blowers or pumps used to cool them. Sulphur-dioxide gas is given off by these burners and is conducted to a Glover tower where it meets dilute acid, which it concentrates, and nitrous vitriol, which it denitrates. Steam is produced in this tower for supplying some of the chamber's requirements, and the hot furnace gases are cooled. The acid from these towers is cooled in one plant by the radiation surface of over four miles of 1½-in. lead pipe.

From the tower the gases are conducted to lead chambers, where in the presence of nitrogen oxides and steam or water vapor, they form sulphuric acid. The remaining gas then passes on to Gay-Lussac towers where the nitrogen oxides are recovered in the form of nitrous vitriol.

The fan which forces the gases through the Glover tower is driven by specially insulated electric motors, which withstand the acid fumes and are only shut down when the furnace linings must be renewed. This program calls for continuous operation for five years or more. At a certain large plant the impellers of these fans, made of antimonial lead, are 8 feet in diameter with ten 4-foot-wide vanes. These impellers weigh 6 tons each.

The nitrogen oxides are made by heating Chile nitrate or niter, as it is called, in retorts with sulphuric acid. The electric motor-driven niter feed device is geared to a chain pump which feeds the right proportion of acid. These retorts are 10 feet high and 8 feet in diameter, and hold 8,000 lb. of sodium nitrate without overflowing.

In one well-known plant the Glover towers are octagonal in shape, 55 ft. high and 30 ft. in diameter from lead wall to lead wall. These lead curtains are lined with chemical brick laid in acid-proof cement. The thickness of these brick walls at the bottom is 22½ inches. The towers are packed with acid-proof tile. The amount of acid pumped over three of these towers by electric motor-operated pumps is 3,600 tons or 72 tank car loads a day. The temperature of the acid discharged from the towers is from 138 to 150 deg. C. (280 to 302 deg. F.), and of the gas escaping from the tower into the chambers about 93 deg. C. (200 deg. F.).

At this plant there are six million cubic feet of lead chambers, eleven of them being 50 by 50 ft. by 67 ft. high and six of them 50 by 50 ft. by 72 ft. high, besides some thirteen others of varying sizes in the first section of this plant, and in the second section the four largest chambers in the world, 59 by 236 ft. by 40 ft. high—556,960 cu. ft of space each.

Instead of steam, as formerly used, water is atomized in these chambers by great sprays capable of atomizing as much as 50 gallons of water per hour each. Centrifugal pumps driven by electric motors using water-power generated current effect a great saving in the cost of fuel by this improvement.

The Gay-Lussac towers at one section of this plant are eleven in number and are of various sizes. Three are octagonal in shape, 62 ft. high by 35 ft. in diameter. Their lead curtains are also lined with acid-proof brick walls laid dry and some of the towers are packed with quartz while others are filled with acid-proof brick or tile. The acid is sprayed over this tile and, as nitrous acid, is collected at the bottom of the tower ready to go through the process again.

Chemistry's Basic Industry Relies on Electric Power

Soda-alkali products are used as raw materials in so many industries manufacturing articles which closely touch our daily lives that a description of their manufacture will prove very interesting, especially since the United States government is now controlling the use of alkali to insure a sufficient supply for war purposes.

Throughout our homes and from our head to our feet, alkali has touched nearly every article. It has gone into window panes and into the glassware on our tables. It has helped to make rugs, carpets, curtains, and the varnish on the woodwork. It is in our kitchen enameled ware and assists in the production of our plated ware, our laundry and toilet soap, and our writing paper. Itself derived from salt, it helps to purify the salt used on our tables. It sweetens our ripe olives and gives the "pep" to our self-rising flour. Our stockings, underwear, waists, dress goods and suitings (whether cotton, wool, or linen), have all met alkali at one time or another. Finally, without alkali we would have practically no dyes. Life would be of somber hue, like the desert where the sage brush grows, grey with the parching dust and stunted by the very alkali which adds so many comforts to our daily life.

To the average person the term alkali conveys no definite idea. The housewife may know of it as "lye," which she uses for cleaning sinks and drains. The traveler may know of it, to his regret, as the irritating dust that sifts in through double Pullman windows as he travels the deserts of Mexico and our own Southwest.

Let us look through eyeglasses made from alkali and see how alkali is used in our industries and then how it is made.

In the manufacture of textiles, alkali is used to clean or mercerize the raw materials and to fix the dyes. In the making of soap, it is used to saponify the fats. It supplies the smooth surface for our writing and printing papers, as well as neutralizes the acid used in the manufacture of paper pulp. Alkali is an important raw material in the manufacture of glass. As bicarbonate of soda, alkali is the principal ingredient of our baking powders.

Sodas, an important family of alkalis, are made by the Solvay process from salt, ammonia gas, and carbonic acid gas. An electric motor-driven pump forces water into a salt deposit beneath the earth's surface. This water dissolves some of the salt and, as brine, it is forced up into storage tanks. Here a float automatically controls the speed of the motor-driven pump. If the brine becomes too concentrated, the float rises and slows down the motor, and, conversely, too weak brine causes the float to sink and speed up the motor.

The ammonia gas is obtained from coke ovens by the process described in the dye section of this article—all the power being supplied by electric motors.

The limestone used is quarried and crushed by electric power and conveyed by electric motor-driven bucket or belt conveyers to kilns which have electric motor-driven blowers. When heated to a high temperature in these kilns, the limestone gives off carbonic acid gas.

Salt brine is saturated with ammonia gas to produce ammoniated brine, which is circulated by electric motor-driven pumps. Carbonic acid gas is then blown into the solution. Crude bicarbonate of soda separates as a white powder and sal ammoniac remains dissolved. These chemicals are separated by electric motor-driven filters and centrifugals.

The crude bicarbonate of soda is heated in a furnace where it loses all of its water and part of its carbonic acid gas. The product is now sodium carbonate, or soda ash, the finished product of the Solvay process and the form in which soda alkali is most used in industry for the manufacture of glass (melted soda ash, lime, and sand), soap (where it is changed to caustic soda), paper, leather, enamel ware, and cleansers. Soda ash is also used in the textile industries, dying operations, water softening, metallurgical operations, bottle and dish washing, refining of vegetable and mineral oils, metal working, and prevention of timber mold.

Soda ash, which is a white finely crystallized powder that can be handled without injury to the skin, is not pure enough for household use. It is therefore recarbonated, that is, carbonic acid and water are put back into it forming again bicarbonate of soda, or cooking soda, which is a beautiful white powder of extraordinary purity running about 99.7 per cent pure. Although an alkali, it has no deleterious effect upon the human system.

Caustic soda is made from soda ash by treating it with milk of lime, "white wash," made by slaking lime in water. The waste lime compound is filtered off and the caustic soda obtained from the remaining solution by evaporation. It is baled into drums where it solidifies to a hard fibrous mass known as solid caustic. When broken up into small pieces, it becomes the "lye" of the housekeeper. Electric power is used for each step of this process and to manufacture the drums used as containers.

Caustic soda is chiefly used in the manufacture of soap, paper, certain chemicals, drugs, paints, and enamel ware, in the tanning of leather, in the textile industries, for mercerizing cotton, water softening, bottle washing, vegetable and mineral oil refining, metal working, battery making, and in the preparation of cleansers where the operator does not come into contact with the solution and where the apparatus is such that it will not be destroyed or attacked by the caustic alkali.

Mixtures of bicarbonate of soda and soda ash are used in the cleansing of fine textile fabrics, in laundry work, and in cloth finishing. These modified sodas are especially efficient for this work because a maximum cleaning action is obtained with a minimum attack on the goods cleansed. They are more soluble in water than soda ash alone and greatly increase the solubility of soaps made from them.

Mixtures of modified sodas containing a small proportion of bicarbonate are used in hand cleansing operations in dairies, bottling works, and in dishwashing machines. They are especially adapted to cleansing tile and marble floors, which if cleansed with soap are left with a darkened appearance and are made very slippery. A mixture of this type is also used to clean unfinished wooden floors. It does not darken the floor nor does it collect in the cracks between the boards and become rancid, developing an unpleasant odor as soap sometimes does when used for this purpose. They are also used to clean white enameled ware, dishes, and in general laundry work.

Chemistry's Control Safeguards the Product in Many Industries

The hand of chemistry is the power behind the throne in many industries, guiding the manufacturing processes and eliminating waste; just as electric power is assuring continuity of operation, at maximum productive speed, from a power standpoint. While not called chemical industries, they are dependent on the skill of chemists.

In our great steel industry, samples of the molten metal are taken and analyzed by a chemist before the furnace or converter is tapped so that the necessary corrections of carbon, manganese, silicon, etc., can be made in time to prevent ruining the entire heat. With the exact results obtainable from the electric furnace, where coke is not the source of heat, we may see the day when steel or chemically pure iron will be made up just as a pharmacist compounds a prescription.

One of the largest single branches of manufacture based upon chemical technology is ceramics—its products being used in every war industry. Chemical analyses of materials and products, as compared with manufacturing routine and performance, are the foundations of chemical control in this industry.

A few of these products are refractories for destroyers and other battle craft; radically new spark plugs for airplane engines; optical glass for sights, range finders, etc.; special glass for searchlight reflectors, port lights, etc.; laboratory glassware and porcelain for control work in all industries; fire brick and crucibles for steel works, etc.; abrasives for machine shops, optical products, etc.; chemical porcelain for explosive, acid, and heavy chemical plants; cement for ships and construction work; limestone and lime for blast furnaces, chemical plants, and buildings; building bricks, terra-cotta and tile, and enamelled iron ware for chemicals, explosives, etc.

Electric power is used in the leading ceramic plants for operating many different types of machines under accurately controllable power conditions. It has speeded up jigger machine production 30 per cent. Motor-operated sagger presses show a 400 to 1000 per cent increased production over that obtained by manual methods of manufacture.

In the paper industry, chemistry plays an important part in the manufacture of sulphite pulp, in assuring the purity of raw materials and the high quality of the finished product

Chips of wood are treated with sulphurous acid or caustic soda in steam digesters to loosen the bond between the fibers. The preparation of the acid and size, the dyes and filters, and the many other elements are all under chemical control.

In the fertilizer industry, chemical knowledge selects all the raw materials and controls at every stage the manufacture of the sulphuric acid used to make acid phosphate.

Certain kinds of meadow peat or muck are drained, the acid neutralized by lime, subjected to the action of aërobic bacteria to fix the nitrogen, and then planted in crops to aërate and eliminate seeds of weeds. This gives us humus, a partly decayed organic matter, the decayed remains of former generations of plant and animal life. As a fertilizer it is most valuable, capable of raising 1000 bushels of onions to the acre, or 500 bushels of potatoes, or 1,000 twenty-four head boxes of lettuce, or 200 crates of celery (120 of which fill a freight car).

Electric power operates the pumps, scrapers, loaders, rotary driers, screens, and grinders.

In the manufacture of rubber, chemists play a most important part in determining the formulas for special rubber to resist certain elements: tires to withstand oil and road wear, mechanical goods to withstand hot water and chemicals, and, recently, gas masks that withstand poison gases, and proofed fabric for dirigibles which must keep hydrogen from diffusing. This industry has necessitated the production of American chemicals to replace those the importing of which was stopped at the advent of war.

Power for the manufacture of rubber goods is supplied by electric motors. These operate rolls to crush the rubber while it is being washed, vacuum pumps to help dry the rubber, while still other motors drive great steam-heated rolls for mixing the rubber with various compounds, such as whiting, barytes, zinc oxide, and coloring matter, such as antimony sulphide, lithophone, etc. The rubber compound is rolled into sheets or forced into canvas by calenders which are driven at any desired speed by electric motors. These machines are stopped, started, and run at any desired speed by simply pushing a button located convenient to the operator. The use of electric power for this work has greatly increased production and improved quality.

In the manufacture of soap and washing powders, the chemist controls the quality and quantity of the raw material, and its use. He finds substitutes for the perfumes which cannot now be obtained and produces soaps for soft and hard waters.

The fats used in soap manufacture are mostly obtained from packing houses where electric power is used to drive conveyors, bristle removers, jaw breakers, fat back skinners, belly rollers, and many other machines necessary in this industry. That these motors operate in an atmosphere of steam and under trying conditions satisfactorily, speaks well for the employment of electric power.

Some of the fats obtained are treated to produce oleomargarine while others go directly into large vats with motor-driven stirrers to be saponified with caustic soda for making soap. At the large packing plants this soap is molded, rolled, wrapped, and packed into boxes entirely by electric power.

In the paint industry, the chemicals are prepared by chemists and mixed in tanks having electric motor-driven stirrers or ground between electrically operated stones.

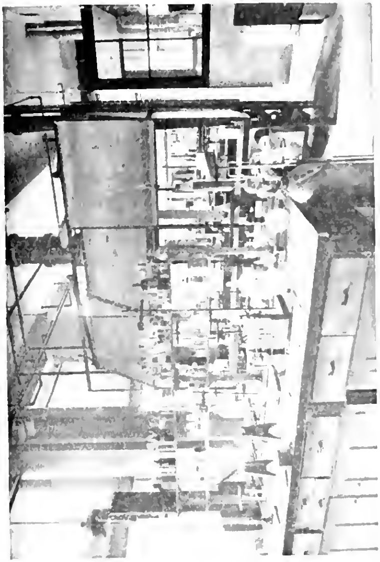
In the shoe and leather industry the chemist is always busy working out new tanning processes to produce leather having special colors or properties, such as oil-resisting, waterproof, etc.

Electric power operates dehairing machines, agitators in liming and tanning vats, fans for drying the leather, and scores of machines for making shoes which cut the leather by dies, sew it into uppers and then into complete shoes, trim and burnish the soles, polish the uppers, etc. Electric motors have greatly increased the production of shoes and reduced the power cost per pair as well as the number of seconds.

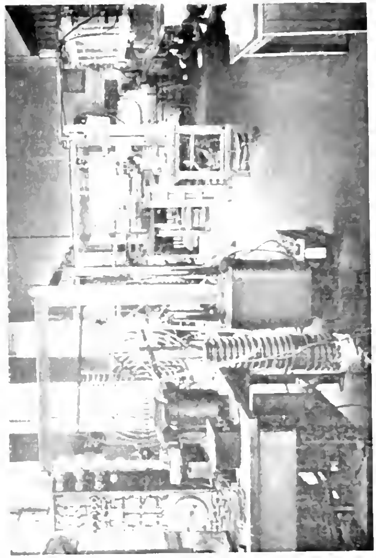
In the cane and beet sugar industry, chemistry plays a part in the neutralizing of the acids in the raw juice and in the renewal of the filtering property of the boneblack, as well as in many other ways, exercising control at many stations in the manufacture of the sugars and molasses.

In the cane sugar industry electric power hauls the cane cars to the central and dumps them on conveyors which carry the cane to the crushing rolls. These rolls are driven electrically at any desired speed, and the operator can instantly adjust the speed to that value which will secure the maximum extraction and output.

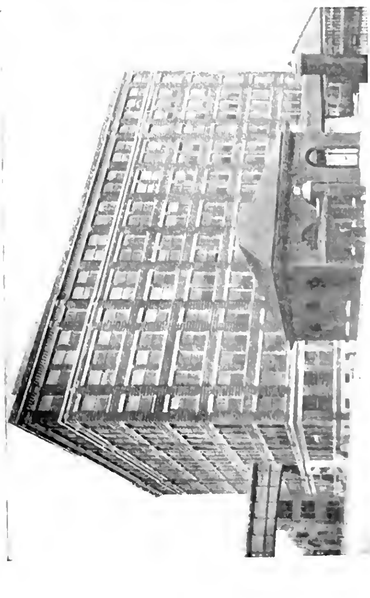
Where beets are utilized, they are conveyed by water to a washing wheel and an electrically driven conveyor elevator which



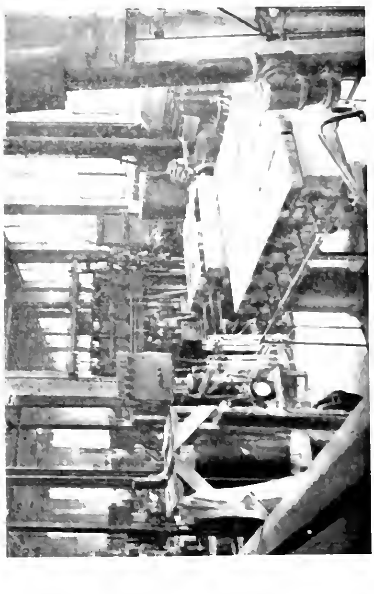
Room in Analytical Laboratory
General Electric Company



Research in High Potential Work



One of the Research Laboratories of the
General Electric Company



One of the Electric Furnace Rooms in Research
Laboratory. General Electric Company

carries them to a machine where they are cut up into little serrated chips called cossettes. These are separated from their sugar by steam and diffusion in large digestors.

The juice from both the cane and the beet is treated with sulphurous acid and with lime to neutralize acids and to form precipitates which are filtered or settled out. It is then further filtered through boneblack, when perfectly white sugar is desired, and evaporated in multiple-effect vacuum pans having electric motor-driven liquid and vacuum pumps. From here the crystalline mass goes to electric motor-driven centrifugals which remove the uncrystallized liquid and allows the crystals to be emptied onto a conveyor which takes them to a crystallizer where they are dried ready for packing. Electric motors drive the conveyors, crystallizers, and the barrel making and jogging machinery.

In the oil industry chemists are directing the refining and producing of many by-products. Here electric power pumps the wells so efficiently that it pays to pump many wells which had been abandoned because of the high cost of steam pumping. This power operates great pumping stations attached to pipe lines which extend through a number of states or which supply tank ships with their cargoes. It is electric power that pumps this oil from still to still, as it is fractionally distilled to produce naphtha, gasolene, kerosene, lubricating oils, paraffine, etc., and this same power operates the box and can-making machinery and the conveyors which carry the product to the ship or the railroad car.

In the cottonseed oil industry the chemist is producing edible oils and fats which are substituted for lard and butter.

Here the seed is linted by electric motor-driven machines to obtain a raw material used in the manufacture of guncotton, and is then cooked and compressed to extract the oil. Electric power-driven conveyors unload the seed from railroad cars for the linters, and operate the hydraulic pumps used in connection with the presses.

Cottonseed oil is refined in big vats with motor-operated stirrers and is pumped from caustic soda chemical treatments to other refining treatments by electric motor-driven pumps. A great saving in power cost and a very real increase in production has been attained by the use of electric power in this industry.

To chemistry is due the entire corn product industry with its valuable oils and food products. Here chemists control every operation in the great vats with their motor-driven stirrers, and electric power drives the big grinding mills.

We might continue on through a hundred industries but enough has been said to indicate the vital importance of chemistry and electricity today.

The Service of an Electrical Research Laboratory

In the research laboratories of the General Electric Company are many scientists working to increase the usefulness of electricity to industry—especially essential war industries.

In one of these laboratories at Schenectady are nearly 70,000 sq. ft. of floor space, with each room piped for water, gas, compressed air, vacuum, high and low pressure hydrogen, oxygen, and high pressure steam, and adjoining are completely manned and equipped machine and forge shops, etc.

In this laboratory research work has been done on paints, oils, and varnishes; irons, steels, and alloys; copper, zinc, molybdenum, and magnesium; kenotrons and pliotrons for radio work; X-ray location of holes in castings; incandescent lamps and searchlights; insulation and brush compounds; turbine blades and boiler feed water; atomic hydrogen; molecular layers in catalyzers; fuse fillers; lithium, boron, uranium, and thorium; rubber and platinum substitutes, sherardizing and calorizing, condenser, boiler and pyrometer tubes and powerful X-ray tubes.

The achievements of these laboratories benefit every man, woman, and child wherever electricity is used. Pure scientific research works hand in hand with the development of new devices, more efficient apparatus and processes of manufacture, and results in the discovery of better and cheaper materials—*all to the end that electricity may help more and more in the winning of the war*—and after that, in making mankind's life happier and more livable.

Acknowledgment for valuable information in the preparation of this article is made to Mr. C. A. Winder, General Electric Company, the authors of papers delivered at the Fourth National Exhibition of Chemical Industries (New York City, week of September 23, 1918) and to Messrs. H. A. Winne and L. S. Thurston, General Electric Company, for reading and correcting proof.

The Ferro-Alloys*

By J. W. Richards

Professor of Metallurgy, Lehigh University; Secretary, American Electrochemical Society
Member, U. S. Naval Consulting Board

It is quite commonly known that the addition of certain metals to steel greatly improves its qualities for special purposes. The customary method of adding these metals to the steel is in the form of an alloy of the metal with iron, these ferro-alloys being now made almost exclusively in the electric furnace. Mr. Richards describes the composition of each of these alloys, the method of manufacture, and the properties imparted to steel by the addition of each of the molten metals. Editor.

A large industry has grown up within the last fifty years, most of it within the last twenty-five years, which furnishes to steel makers alloys of iron with some of the rarer metals, in order to introduce these rare metals into steel. Such alloys are known as ferro-alloys, because they all contain iron (ferrum); some of them, however, contain more of the rare metal than iron. They were originally made in crucibles, cupolas, or blast furnaces, but are now made principally in electric furnaces, and their manufacture is one of the principal electric furnace industries.

They are of great importance to the steel industry. The steel maker uses them for one of two purposes: (1) As reagents to take oxygen out of melted steel and thus insure sound solid casting (ferromanganese, ferrosilicon, ferroaluminum); or (2) to put into the steel a small or large percentage of the rare metal (ferromanganese; ferrochromium, ferrotungsten, ferromolybdenum, ferrovanadium, ferrotitanium, ferrouranium, ferroboron).

Let us discuss briefly these two uses. Melted steel, just before taking from the furnace, always contains some oxygen dissolved in it (like the dissolved gas in charged soda water). If this is not removed, the casting made is more or less unsound from cavities or blowholes. The addition of a small amount of a metal with a high affinity for oxygen removes this element and makes the casting sound. Manganese (1 per cent or less) is the cheapest and most generally used reagent for accomplishing this; silicon ($\frac{1}{2}$ per cent or less) is more powerful but also more expensive, and is often used to supplement the action of manganese; aluminum (0.1 per cent or less) is still more powerful and still more expensive, and is used in very small quantities as a final addition to complete the action of the manganese and silicon. All steel makers use one, two, or all three of these reagents; manganese and silicon in the form of ferro-alloys, aluminum more often as the pure metal, but ferro-aluminum is sometimes used.

The second use is to make special steels, that is, steels containing such quantities of the rare metal as give to them properties different from plain carbon steels deoxidized by manganese, silicon, or aluminum. Thus we may make manganese steel by putting in 12 to 14 per cent of manganese, making a very tough, hard steel such as is used in mining and grinding machinery, burglar-proof vaults, etc.; chromium (2 to 4 per cent) makes a very hard tool steel; tungsten (15 to 25 per cent) makes high-speed tool steel which cuts iron while red-hot; molybdenum (6 to 10 per cent) has powers similar to tungsten, and is also used in steel for lining large guns. Vanadium ($\frac{1}{10}$ to $\frac{1}{2}$ per cent) makes very strong steel which resists shock extremely well, as when used for automobile axles; titanium, uranium and boron impart valuable properties not so easily described. Every one of these materials is used for producing some specific result which is not produced by any other; sometimes combinations of two, three, or four are used in one steel, producing a particular combination of special properties for some special purpose. Some of these materials cost $5 per pound, and the special steels produced cost up to $2.50 per pound, but their particularly valuable properties justify the expense. The value of these special steels to the industries, and particularly for military purposes, is very great, so great that the supply of ferro-alloys for their manufacture is an important factor in winning the war.

Ferromanganese

This is the oldest of the ferro-alloys. Its manufacture was begun about 50 years ago. It was first made in crucibles, has for a long

* A paper read at the Fourth National Exposition of Chemical Industries, New York, Sept. 27, 1918

time been made in blast furnaces, but is now being produced in many places in electric furnaces. It is made with 30 to 85 per cent manganese, 3 to 5 per cent carbon, a little silicon, and the rest iron. The rich grades, 75 to 85 per cent, are preferred by the steel maker, but they require rich manganese ores for their manufacture. The United States has very little rich manganese ore, but large quantities of low-grade ores; one of the present burdens of the steel maker is to use low-grade ferromanganese, in order that we may not have to use ships for importing the high-grade ores from Brazil.

The usual manufacture in blast-furnaces is wasteful of both fuel and manganese; the furnace must be run hot and slowly, with very hot blast in order to reduce the manganese oxide ore as completely as possible and not waste manganese in the slag. Yet, in spite of all efforts, from 15 to 25 per cent of the manganese going into the furnace escapes reduction and is lost in the slag. This waste of fuel and manganese has led to the use of the electric furnace, in which fuel is required only as a chemical reagent and not to produce heat, thus saving about two thirds the fuel requirements of the blast furnace, while the higher temperature available causes the extraction of manganese to reach 90 per cent, i.e., slag losses to be down to 10 per cent or less. Against these economies must be set the considerable expense for electric power and the smaller scale on which the furnaces run. At the present high prices of coke and manganese ore, and in view of the scarcity of manganese and the high price of ferromanganese, the electric ferromanganese industry is able to exist and make large profits. Whether it can do so when normal conditions return, after the war, is questionable; it is to be hoped that it will be able to do so, because of the economy which it undoubtedly possesses in regard to fuel and manganese.

Steel producers use ferromanganese particularly for making the low carbon or soft steels, because they can thus introduce the required manganese for deoxidation without putting in considerable carbon. For higher carbon steels spiegeleisen (15 to 20 per cent manganese), a cheap blast furnace alloy, can be used, and is being used at present wherever practicable, in order to save ferromanganese. The best practice with either spiegeleisen or ferromanganese is to melt them in a small electric furnace, and tap from it the required weight to be added to the heat of steel. The melted alloy mixes quicker with and reacts more actively upon the melted steel, while less of it is necessary because less is oxidized by the furnace gases. The saving in manganese by the use of the electrically melted ferro is alone sufficient to justify the expense of melting it in an electric furnace, while better and more homogeneous steel is produced.

Ferrosilicon

This alloy may run 15 to 90 per cent silicon, but the most commonly used is the 50 per cent grade. It is made from ordinary silica (quartz or sand), reduced by carbon in the presence of iron ore or scrap iron. The blast furnace is able to make only the lowest (15 per cent) grade, because silica is exceptionally difficult to reduce, and under conditions which would reduce 99 per cent of the iron ore in a furnace, or 75 per cent of the manganese ore, only 15 to 20 per cent of the silica present can be reduced, and only a low-grade silicon alloy produced. The higher grades must all be produced in the electric furnace.

The raw materials are ordinary silica, the most abundant metallic oxide on the earth's surface, iron ore or scrap iron (iron or steel turnings or punchings), and coke. Electric furnaces up to 10,000 h.p. have been operated on ferrosilicon (50 per cent grade). At the high temperature required, a not inconsiderable proportion of the reduced silicon vaporizes, and burns outside the furnace to a white silica smoke. This can be largely prevented by skillful furnace supervision. In normal times, the 50 per cent alloy sells at $45 to $50 per ton, which is a low price for an alloy so difficult to produce.

Steel producers use ferrosilicon principally for the great activity with which the silicon removes dissolved oxygen from the steel. It is about four times as active as manganese in thus reducing blow-holes and producing sound castings. It is usual, however, to use manganese first, to do the bulk of the deoxidation, and silicon afterwards to finish up the reaction more completely. It is particularly useful in making sound steel castings which are cast into their ultimate form and do not have to be worked into shape, because a slight excess of silicon may make the steel hard to forge or roll, whereas an excess of manganese does not have so bad an effect on the working qualities. A particular kind of steel called silicon steel carries 1 to 2 per cent of silicon and yet forges well; this would be classed as a special steel.

The ferrosilicon industry has attained large proportions in countries where electric power is cheap, particularly therefore in Switzerland, the French Alps, Norway, Canada, and parts of the United States. Under present conditions it is even profitably run where electric power is relatively dear, as at Anniston, Ala., and Baltimore, Md. It is a large, interesting, and rapidly growing industry.

Ferroaluminum

This alloy, with 10 to 20 per cent of aluminum, was made in the electric furnace and used in considerable quantity in steel about 1885-88, but was displaced by pure aluminum as the latter became cheaper. Aluminum is about seven times as powerful as silicon and twenty-eight times as strong as manganese in acting upon the oxygen dissolved in steel; therefore only minute quantities are necessary, say one ounce up to a maximum of one pound of aluminum per ton of steel. Its use gives the finishing touch to the deoxidation of the steel.

About 1885 the Cowles brothers, operating the first large electrical furnaces run in America, at Lockport, N. Y., made and sold considerable quantities of ferroaluminum, selling the aluminum in it at the rate of about $2 per pound, while the pure metal was then costing $5. When, a few years later, pure aluminum sold for 50 cents per pound, the steel makers turned to using the pure metal instead of ferroaluminum, and at the present time aluminum is so used in practically every steel works in the world.

There seems to me a distinct opportunity for makers of ferro-alloys to revive the manufacture and sale of ferroaluminum. Such great advances have been made in the construction and operation of large electric furnaces since 1890, and so much experience has been had in reducing the difficult oxides to ferro-alloys, that the production of 50 per cent ferroaluminum at say $100 per ton may be a distinct electric furnace possibility. That would furnish the contained aluminum at about 10 cents per pound, as against 30 cents for the commercial aluminum now used. The alloy should be broken up small before using, and thrown in the runner or on the bottom of the ladle, in order that the melted steel may quickly dissolve it as it runs into the ladle.

Such ferroaluminum would require bauxite with iron ore or scrap iron for its manufacture, but there are large deposits of low-grade bauxite rich in iron, in southern France, which could be reduced directly to the alloy without any additions, and thus furnish very cheap raw material for the operation.

In conclusion, ferroaluminum is not now being made, but its electric furnace production is a real possibility.

Ferrochromium

Ferrochromium is used for making what is familiarly but erroneously called "chrome steel." It makes steel exceedingly hard. Very hard cutting tools, and armor plates to resist projectiles, are made of it. Only 2 to 4 per cent of chromium may be used.

Several grades are made in the electric furnace, depending on the per cent of chromium (25 to 75), and the content of carbon (2 to 8 per cent). This alloy takes up carbon so actively in the furnace that it has to be treated subsequently to remove the carbon down to what can be endured by the steel into which it is introduced.

The raw material for its manufacture is chromite, an oxide ore of both chromium and iron. If this is mixed with carbon and smelted in the electric furnace it reduces directly to ferrochromium alloy (often misnamed "ferro-chrome"), and highly saturated with carbon (6 to 10 per cent). Steel makers want lower carbon than this, so the alloy is remelted with more chromite in another furnace, and the excess of carbon oxidized out. The low carbon alloy sells for 2 to 3 times the price of the high carbon crude material.

The cutting off of importations of high-grade chromite ore from Asia Minor has led to intense prospecting in the United States. Fair material has been found in many places, and at present our country is nearly independent of foreign sources of the ore

Ferrotungsten

Tungsten (also called wolfram) imparts curious and valuable properties to steel. A small amount (2 to 5 per cent) has been used for half a century or more, to make the steel self-hardening; that is, a tool of this steel need only be let cool in the air, and it becomes hard without the ordinary quenching or chilling operation. Larger proportions (10 to 25 per cent) make a steel which stays hard even when red hot. A tool of this material can be run so fast on a lathe, for instance, that it gets red hot from the friction and work, yet keeps hard and keeps on cutting. It is called high-speed tool steel.

and its use alone has more than doubled the output capacity of the machine shops of the world.

The ore used is either wolframite, a black oxide of iron and tungsten, or scheelite, a white oxide of calcium and tungsten. It is found in considerable quantities in Colorado, and some other western states, and imports of this ore have not been necessary during the war. In this respect we are much more favorably situated than the European nations. A plentiful supply of tungsten ore may indeed be regarded as a large factor in the production of cannon and firearms and all kinds of machinery, and therefore a considerable factor in winning the war.

Ferromolybdenum

Molybdenum has only recently come into large use in steel. Its action being somewhat similar to that of tungsten, scarcity of the latter metal, particularly in Europe, has led to the manufacture of ferromolybdenum on a comparatively large scale.

The ores are widely distributed but not very plentiful. Molybdenum sulphide, molybdenite, looks almost exactly like shiny graphite but it is a shade lighter in color and nearly twice as heavy. It occurs usually as flakes in granite rock and might easily be mistaken for graphite. Lead molybdate, wulfenite, is a compound of lead and molybdenum oxides, a very prettily crystallized yellow to red mineral in thin square plates. It occurs abundantly in a few lead mines in the West. It is usually first treated to extract its lead, and the residue then worked for molybdenum. The sulphide used to be roasted to molybdenum oxides, and this reduced by carbon in the presence of iron ore or scrap iron in an electric furnace. It is now smelted directly in the electric furnace with carbon and a large excess of lime along with iron ore or scrap iron. Ferro with 50 to 60 per cent of molybdenum is tapped from the furnace like other ferro-alloys, but with molybdenum up to 80 per cent the alloy has such a high melting point that it cannot be tapped out without freezing; it is necessary to make a furnace full of this alloy and then let the furnace cool down and take it apart, taking out a large mass of solidified alloy; the furnace is then rebuilt.

The large use of molybdenum in steel has been so recent that not much has been made public about it. Rumor says that the large German guns which bombarded Liege (the "Black Berthas") were lined with molybdenum steel (6 to 7 per cent) to increase their resistance to erosion. It seems certain that Germany drew considerable supplies of molybdenite from Norway to compensate for shortage of tungsten for high-speed tool steel. Parts of guns, gun carriages, motors, automobiles, have also been made of molybdenum steel of most excellent quality. Canada has been especially active in the manufacture of ferromolybdenum steel, most of which is exported to Europe. This alloy is therefore another valuable war material.

Ferrovanadium

Without vanadium the modern automobile or auto-truck would be a much weaker machine. When steel is desired to withstand the heaviest shocks and vibration, nothing is quite so effective as adding vanadium. This is another comparatively rare metal, found principally in the radium ores of Colorado and as a black sulphide in the highlands of Peru. The canary yellow Colorado ore is treated for radium, and the residues for vanadium and uranium. The U. S. Government (Bureau of Mines) operated this process for the radium supply. The black ore of Peru is rich and unusual; it is a sulphide with some asphaltic matter, and it is roasted to the condition of iron-vanadium oxide before reduction. The oxides are best reduced by metallic aluminum. This is the well-known thermit (Goldschmidt) method of reduction. Electric furnace reduction by carbon is not advantageous because of the large amount of carbon taken up by the alloy; powdered silicon is therefore put into the charge as the reducing agent, together with iron, lime, and fluorspar, and then a 30 to 40 per cent vanadium alloy is obtained with seldom over 1 per cent of carbon, a very desirable composition (R. M. Keeney).

Only small amounts of vanadium are necessary to improve steel; 0.1 to 0.4 per cent are the usual quantities. This is fortunate because the vanadium costs $5 per pound and over. Metallurgists suspect that part of the improvement of the steel may be due to the vanadium combining with and removing nitrogen dissolved in the melted steel. This is probably true, yet some advantage undoubtedly must be ascribed to the final vanadium content in the steel; both avenues of improvement function. Steels thus treated are unusually resistant to shock and alternate stresses, making them very useful for axles, cranks, piston-rods, and such severe service.

Ferrotitanium

Titanium is an abundant element in nature. It occurs in immense amounts as a double oxide of titanium and iron, known as ilmenite, or titanic iron ore. This ore can be reduced directly by carbon in electric furnaces to ferrotitanium. The reduction proceeds easier if some aluminum is put in as a reducing agent, but this is expensive and unnecessary. The alloy running 15 to 25 per cent titanium is sold for use in steel as a refining agent to remove oxygen and nitrogen. Thousands of tons of steel for rails has been thus treated, the tests showing considerable improvement in the mechanical properties by the use of quite small amounts (0.10 to 0.20 per cent) of titanium.

Ferroboron

This is another alloy whose valuable qualities have not yet been entirely determined. Boron is the metallic base of borax, which is a sodiumboron oxide. Borax is very difficult to reduce to the metallic state. Another raw material, not so abundant, is colemanite, containing lime and boron oxide. Many attempts have been made, none very successfully, to reduce this with iron oxide to ferroboron. The American Borax Co. offered a prize, for several years, for a process which would accomplish this. Boron oxide occurs rarely in nature, but it can also be manufactured from borax and colemanite. When the oxide is obtained, this can be combined with iron oxide and the resultant boron-iron compound reduced by carbon in the electric furnace to ferroboron. Small quantities of this alloy have thus been manufactured.

Experiments on steel have shown that ferroboron acts somewhat similarly to ferrovanadium. Experiments in France showed remarkably strong and tough steels were thus made, using 0.5 to 2 per cent of boron. The results have not been properly followed up, partly on account of the difficulty in getting ferroboron; no one, as yet, has taken up its regular manufacture and steel makers can hardly be blamed in these stirring times for not having as yet thoroughly explored its possibilities as an addition to steel.

Ferrouranium

This is the latest of the ferro-alloys to enter the lists. Uranium is a very heavy and, chemically, very active element. It is found very scarcely as a black oxide, the mineral pitchblende—the mineral in which radium was first discovered. It is found more abundantly in the Colorado radium ore, a bright yellow oxide and silicate of vanadium, uranium, and lime. After extracting the radium and vanadium, the uranium remains in the residue as a by-product, usually as a soda-uranium compound. This is treated so that uranium oxide is obtained, and this can be reduced by carbon in an electric furnace in the presence of iron ore or scrap iron, to ferrouranium (30 to 60 per cent). The recovery of uranium is not high (50 to 70 per cent) the rest being lost in the slag. Mr. R. M. Keeney has recently described these processes in detail, for the first time in the August *Bulletin* of the American Institute of Mining Engineers.

The results of tests showing the influence of uranium on steel are not yet completely known. Some firms have claimed for it wonderful strengthening power and resistance to shock. The subject is still receiving expert attention from steel makers, and valuable results are confidently expected.

Conclusion

The ferro-alloys are exceedingly important materials to the steel maker, either in the making of ordinary steel or for producing special alloy steels. They are indispensable to the steel industry. They are important factors in producing both ordinary and fine steels, and therefore in winning the war. The country well supplied with them has a great advantage over the country in which they are scarce. They are deserving of all the expert attention which they are receiving from the War Industries Board, the steel makers, and the economists. The possession by the United States of large supplies and resources in the ferro-alloy line, may be one of the important factors in determining the quick ending of the war.

Electrolytic and Electrothermic Processes and Products

The science and application of electrolysis and electrothermics are so very extensive and are changing so rapidly that it would be almost impossible to give a complete up-to-date review of the subject, and as is only natural, many of the latest developments are secrets closely guarded. Therefore, this article attempts only a very brief outline of the more common electrolytic and electrothermic processes and their products. The subject is of great interest, especially at the present time, and the layman little appreciates to what extent we are indebted to this art for many of our everyday materials, much less the degree to which it serves the government in supplying the materials of war. Information derived from published works and from articles in the technical press has been freely used.—EDITOR.

THE ELECTROLYSIS OF FUSED SALTS

All of the metals which are derived today in commercial quantity from their fused salts by electrolysis are those exceptionally electropositive metals, which either cannot be obtained at all in appreciable yields by strictly chemical means, or can be obtained thus only with great difficulty and at great expense. Thus, magnesium and calcium have been obtained only in recent years, and electrolytically, while sodium, potassium and aluminum (which were formerly manufactured by expensive chemical methods) are also now made entirely by electrolytic means.

The Manufacture of Sodium

Sodium is obtained at the cathode by the electrolysis of either fused caustic soda ($NaOH$) or of fused common salt ($NaCl$). The former is of advantage because of its much lower melting point, and because of the fact that the escape of the gas freed at the anode does not have to be considered. Chlorine gas on the other hand cannot be allowed to escape promiscuously, and so must be used to make bleach, or collected for government purposes. The Castner process, which employs $NaOH$, is the best known, and is operated in America at Niagara Falls by The Electrochemical Company.

The principal details of the Castner cell are shown in Fig. 1. The current enters through the iron anode which surrounds the top of the vertical iron cathode. This cathode extends up through the bottom of the cell, passing through a cast-iron pipe or collar which is attached to the bottom of the cast-iron box which holds the molten electrolyte. The space between cathode and iron pipe is sealed by filling it up with the melt which is then allowed to freeze. A fine nickel gauze diaphragm is inserted between anode and cathode to prevent globules of sodium from reaching the anode and reacting with the water vapor formed there. The molten sodium is collected inside of the chamber from which the gauze diaphragm is hung. In practice the charge is kept in a molten state by proper regulation of the current density. Heat radiation is reduced by suitable brick lagging. The electrolysis must be performed at a fairly constant temperature of 315 to 320 deg. C. This is only 15 to 20 deg. C. above the melting point of the caustic soda. Even at 325 deg. C., the yield falls nearly to zero.

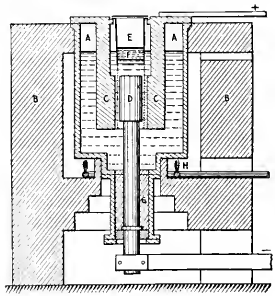


Fig. 1. Castner Sodium Furnace
A, Cast-iron pot set in brickwork B; C, Nickel anode; D, Cathode; E, Metal cylinder receptacle for sodium; F, Liberated sodium.

About 4.5 volts (2.2 volts decomposition voltage) are required per cell, and a direct current of 13 to 17 amperes per square inch is used. The current efficiency is probably about 45 per cent and the energy efficiency about 22 per cent. About 0.56 metric tons per horse power year is estimated from the data at hand.

The main cause of the low efficiency is due to the fact that water is formed at the anode, which, if it does not react with sodium already deposited (which is apt to reach the anode occasionally), is itself decomposed into oxygen and hydrogen to greater or less extent.

In passing, mention should be made of a process due to Ashcroft which has, however, not been attempted commercially. A current efficiency of about 90 per cent and an energy of about 30 per cent are claimed. First, fused $NaCl$ is electrolyzed, using a molten lead cathode. The lead-sodium alloy is then made the anode in another cell where fused $NaOH$ is the electrolyte. The formation of water is thus prevented at the anode (because of the reaction between sodium ions and hydroxyl ions, forming $NaOH$), and sodium is obtained at the cathode.

Most of the sodium made is used to manufacture sodium cyanide and sodium peroxide. The metal has also been tried for drying transformer oils. About 2000 tons were made in the United States annually before the war, no imports being reported.

The Manufacture of Calcium

At the present time calcium is made in this country only by the General Electric Company for its own use. The cell comprises an iron box with water-cooled bottom, through which projects an insulated conical iron cathode. Inside the box and insulated from it is an annular carbon lining which serves as anode. The temperature of the bath and of the cooling water is so regulated that the iron bottom is covered with a thin protective layer of solidified salt. The deposited metal is drawn in stick form as soon as formed and sufficiently solidified, at a speed equal to the rate of deposition. At least one advantage of this method of removing the deposited metal is the smaller tendency for metal fogs.* Again, the metal is at once obtained in pure, solidified massive form.

The electrolyte consists only of fused calcium chloride ($CaCl_2$) held at a temperature of 780 to 800 deg. C. It is estimated that one of these cells may take as much as 25 volts, the decomposition voltage being only 3.24 volts. However, the very high current density of 650 amperes per square inch is used, which would account for the high voltage. Practically 80 per cent of the potential drop is at the cathode. From this data, assuming a current efficiency of 80 per cent, an energy efficiency of only 10 per cent is obtained. The yield per horse power year is thus only 0.1 metric tons. But little information has been published about the process.

* The phenomenon known as "metal fog" sometimes occurs at excessive temperatures and under reducing conditions. Addition of oxidizing agents to the bath, or of even neutral salts in some cases, will destroy the fog. The explanation of the phenomenon is not certain. It consists, however, in the sudden rise from the molten metal (cathode) into the fused electrolyte over the metal of dark clouds whose color depends upon the nature of the cathode metal. These clouds seem to dissolve in the melt. It is probable that the clouds consist of colloidal suspensions of very finely divided particles of the fused metal. The effect of the fog is to reduce the current efficiency of the process, because the metal in the colloidal form (let us assume) is especially susceptible to chemical attach.

The present output per year is small (probably not over 250 lb.) because about the only application of the metal is in the manufacture of calcium hydride (CaH_2), which is used sometimes for generating hydrogen.

The Manufacture of Magnesium

Before the war magnesium was not manufactured in America, our entire supply being obtained from Germany. Now at least four concerns in this country are fully familiar with the process of manufacture and an ample supply is assured.

The metal is used in the preparation of alloys, flashlight powders, etc., and is marketed in both powder and stick form. For an electrolyte a mixture of fused dehydrated carnollite (KCl, $MgCl_2$, $6H_2O$) plus one mol of salt ($NaCl$) is used. During the electrolysis $MgFl_2$ is added, and a certain amount of calcium fluoride (CaF_2). The temperature of the melt is probably 750 to 800 deg. C. From laboratory experiments, a current efficiency of 75 per cent may be assumed. The energy efficiency is probably below 10 per cent. An average of 9 volts per cell is estimated. Available data would indicate a yield of about 0.37 metric tons per kilowatt year.

The Manufacture of Aluminum

The only producer of aluminum in the United States is the Aluminum Company of America, who operates huge plants at Niagara Falls, Massena, Baden, S. C., and Shawinigan Falls (Canada). In America the Hall process is used, while in England and on the continent the somewhat similar Heroult process is worked.

The dimensions of the Hall cell now used are not available. The cell consists of a rectangular cast-iron box, lined with carbon which acts as cathode until the bottom is covered with the molten aluminum, which then serves the same purpose. The current is led into each cell through a series of graphite rods which are distributed uniformly in the cell, dipping down into the fused electrolyte almost to the layer of molten aluminum at the bottom. The molten aluminum is removed periodically by tapping. The fused electrolyte consists of cryolite (AlF_3, $3NaF$), to which enough pure aluminum fluoride (AlF_3) is added to bring the melt to the formula AlF_3, $2\ NaF$ and of pure alumina (Al_2O_3). The alumina is the solute and the cryolite the solvent, just as copper sulphate is the solute and water is the solvent in an aqueous solution. As in the aqueous solution the copper sulphate is decomposed, so in the fused melt the alumina is decomposed into aluminum at the cathode and oxygen at the anode. The decomposition voltage of Al_2O_3 is less than that of either NaF or AlF_3, which explains why it and not its solvent is electrolyzed. Alumina has to be continually added to the melt to compensate for that decomposed.

The normal current efficiency is supposed to be 90 to 95 per cent, but in many works it is not over 65 per cent (Mineral Industry, 1911). An average efficiency of 75 per cent is about right. With a voltage drop of 5 to 6 volts per cell (assuming 2.2 volts decomposition voltage), this would bring the energy efficiency to around 30 per cent. The yield per horse power year then amounts to about 0.3 metric tons. (The Mineral Industry, 1905, gives 1.75 lb. per horse power day, which equals 0.34 metric tons per horse power year.)

Much of the loss is due to metal fog formation, the temperature of the bath being some 900 to 1000 deg. C., which is maintained by the heating effect of the current, while aluminum melts at about 665 deg. C. The anode losses are high, as the oxygen liberated at the anode reacts with the graphite, forming carbon monoxide before escaping. The anode effect* has always to be guarded against by keeping the bath in proper working condition.

The Heroult process was worked out by Paul L. V. Heroult independently and practically simultaneously with Hall. The principle is the same as in the Hall process. The cell is circular instead of rectangular, and the individual anodes are of much heavier cross section. Each cell takes about 7000 amperes at 7 volts.

Aluminum is indispensable in the construction of airplanes and airplane motors, and the war demands of the government have greatly increased its production.

Aluminum is also of great value in the electrical industry. It is used in transmission line construction, and in apparatus where lightness is a desired factor. It is used both as a deoxidizer for steel, and as a principal constituent in many nonferrous alloys. It has found wide application in the manufacture of cooking utensils. In the words of the late Paul L. V. Heroult, "It looks probable that in a course of ten to fifteen years the consumption of the new metal will be equal to that of copper, and that after the golden age, the stone age, the bronze age, and the iron age, we will have the aluminum age."

Figures showing the change in the cost of aluminum, as first chemical methods and then electrochemical methods were developed and perfected, are of interest.

Year	Price per Pound	Method of Reduction
1855	$90.00	Old chemical (St. Claire Deville)
1856	27.00	
1857	22.50	
1862	12.00	
1886	12.00	
1888	5.00	New chemical (Hamilton Y. Castner)
1889	4.00	
1889	2.00	Electrochemical (C. M. Hall)
1897	.35	
1911	.20	

ELECTROTHERMICS

Electrothermics as a science has indicated methods of chemical synthesis and of decomposition through the agency of electric heat. It has been the means of developing several distinctive types of electric arcs and electric furnaces, by which the necessary heat could be obtained and suitable reaction chambers provided. Many new compounds and metals have thus been discovered and commercialized, which would otherwise have remained either unknown or in partial obscurity. Again, several products have been manufactured better and cheaper in the electric furnace than in the previously used fuel fired furnaces.

In brief, the advantages of the electric furnace are:

(1) The temperature that may be attained is limited only by the melting point of the refractory lining of the furnace or by the working temperature of the electric arc. The temperature of the arc is 3600 to 4000 deg. C. Most refractories begin to melt at about half of this temperature. However, as high a temperature as 3000 deg. C. is attained in the core of the Acheson carborundum resist-

* The anode becomes covered with a film of gas (such as chlorine or fluorine) through which the current is able to pass only by the aid of the formation of a great number of minute arcs, which play between electrode and electrolyte. The effect may be overcome generally by reversing the current momentarily, or by some mechanical means. It is more pronounced in case of fluorides, both simple and complex, such as cryolyte, which, as we have stated, is used as the solvent for alumina. In the early days of the industry, a bath has been known to freeze up due to this effect, and this generally always happens in case of any laboratory experiment on a small scale.

ance furnace, the core consisting largely of graphite, especially at the end of the furnace run.

(2) The temperature is under complete control at all times, being determined by the energy input.

(3) The atmosphere in the electric furnace may be made oxidizing, reducing, or neutral at will.

(4) The electric heat can be generated at the point where it is desired.

(5) The thermal efficiencies of electric furnaces are consequently relatively high, while fuel furnaces, with the exception of the blast furnace, show efficiencies under 12 per cent.

A temperature of 2000 deg. C. is about the maximum temperature that can be reached in any fuel furnace. Moreover, as in all cases the gases of combustion (often harmful to the charge in the furnace) have to be taken care of, thus making it very difficult or even impossible to control the atmosphere in a fuel fired furnace, the necessity of an electric furnace for temperatures over 2000 deg. C. and its superiority for lower temperatures are at once evident. The cost of fuel as compared with the cost of electric energy at the furnace, the advantage of a pure furnace product, the increased safety of operation, together with other factors, all go to determine the type of furnace best suited to the conditions that prevail.

Electric furnaces may be classified according to types as follows:

(1) *The Arc Furnace.* This type is represented by most of the modern electric steel furnaces.

(2) *The Resistance Furnace.*

(a) Conducting charge with electrolysis. (The sodium, calcium, magnesium, and aluminum cells, in which the joule effect is used to keep the salts molten.)

(b) Conducting charge without electrolysis. (The Acheson graphite and the carborundum furnaces, the cyanamide furnace, the Hering "pinch effect" furnace.)

(c) Non-conducting charge, heated by a special resistor. (Most laboratory furnaces.)

(3) *The Induction Furnace.*

Before any of the electrothermic processes are discussed in detail, it may be well to consider the more common raw materials that are used in the manufacture of electric furnace products, as well as some of the products obtained. The most useful of all is the element carbon, which is used in several forms. It is the cheapest, best known, and most general reducing agent. In furnace charges, it is used generally in the form of charcoal or coke. Its use in electrodes, as carbon or as graphite, is of equal importance. Carbon in one form or another enters into practically every electrothermic process. From other very cheap materials, such as silica (SIO_2), unslaked lime (CaO), and nitrogen and oxygen from the air, which is free to all, compounds are made by simple reaction with carbon or by application of heat alone, which, before the application of electrothermics, were in many cases unknown to mankind. Thus, carbon and lime produce calcium carbide, which, in turn (when treated with nitrogen) produces calcium cyanamide. Further, the cyanamide can be converted to ammonia by treatment with steam, thus furnishing the base for the manufacture of ammonium compounds. The uses of calcium carbide for the preparation of acetylene, and of calcium cyanamide as an artificial fertilizer need no comment.

An interesting process is the result of the reaction between carbon and silica at high temperatures (1600 to 2200 deg. C.). According to the type of furnace used and the conditions maintained, silicon (Si), siloxicon (Si_xC_yO), carborundum (SiC), and finally graphite may be obtained. In practice, however, graphite is converted directly from carbon through the aid of a small percentage of ferric oxide, or other catalyzer, which is finally volatilized from the graphite. Carborundum, perhaps the best known product, is produced in the United States by the Carborundum Company of Niagara Falls. As is well known, the material is used extensively as an abrasive in the form of wheels, stones, powder, and polishing papers.

Again, carbon (coke), sand, and calcium phosphate, properly mixed and heated in a suitable type of electric furnace, yield phosphorus (a poisonous element) in a manner satisfactory as to yield, and in full safety as regards the health of the workmen. Over half of the world's production is now made in the electric furnace.

The manufacture of carbon bisulphide (CS_2) is also effected electrothermically in an economic and safe manner in the furnace patented by E. R. Taylor. Coke and sulphur are caused to combine under the influence of heat from an arc, forming directly the bisulphide which is distilled off, condensed, and collected.

As a final example of a strictly electrothermic process mention should be made of the manufacture of nitric acid (or of nitrates and nitrites) from the oxide of nitrogen (NO_2), obtained through the combination of

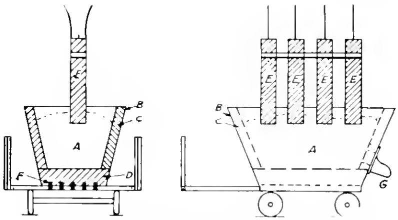


Fig. 2. Calcium Carbide Furnace of the Tapping Type
A, Charge; B, Steel shell; C, Brick lining; D, Carbon and tar hearth; E, Electrode bundle; F, Steel grating; G, Tapping hole.

nitrogen and oxygen at the excessively high temperature of the electric arc. At least three arc furnaces, viz., the Birkeland-Eyde, the Pauling, and the Schonherr are now in commercial operation at places where electric energy can be bought or generated at low rates. The nitrates are used in both the fertilizer industry and the explosive industry, but it is probable that, except in certain localities, the product will go into the latter rather than into the former, because of the competitive cyanamide process, referred to previously, which can fix nitrogen more cheaply, unit for unit.

A few typical processes will now be considered more in detail.

Calcium Carbide (CaC_2)

Calcium carbide was one of the earliest commercialized electric furnace products, being made by Willson in North Carolina, in 1892. In Europe, where the discovery was made simultaneously by Moissan, the industry spread so rapidly that in 1899 many companies failed because of excessive production. This condition has changed, due to the increasing use of acetylene gas, and to the use of the carbide in the manufacture of cyanamide.

The formation of calcium carbide is represented by the reversible reaction shown in (a); however, simultaneously the two side reactions shown in (b) and (c) occur. In each case, as the temperature is raised the reaction proceeds to the right.

(a) $CaO+3\ C=CaC_2+CO$
(b) $CaC_2=Ca+2\ C$
(c) $CaO+C=Ca+CO$

The charge consists generally of good quality lime (56 parts) and low ash (under 3 per cent) anthracite (36 to 39 parts), crushed to pieces one or two inches in diameter. Coke is generally used. Phosphorus should be avoided and the sulphur kept low.

The product is not pure CaC_2, which in reality is a colorless, transparent substance, but is a dark grayish black crystalline material, containing about 15 per cent lime and carbon, and also impurities in small amount retained from the original charge.

Calcium carbide furnaces are all of the arc type, but vary greatly in capacity and in the method of operation. A furnace of the tapping type is shown in Fig. 2. In order to supply the large currents used (28,000 amperes at 50 volts) it is customary to use a bundle of electrodes. A carbon-tar mixture is tamped in the bottom over some steel grate bars, forming a conducting hearth. The electrode contacts are water-cooled. Each unit is mounted on wheels and a tap hole is provided for drawing the sluggish molten carbide. Some furnaces of similar construction do not

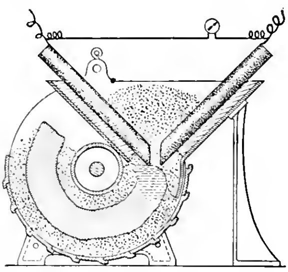


Fig. 3. Continuous Type Calcium Carbide Furnace

possess the tap hole, in which the operation is intermittent, the charge being removed after solidification. The furnace used for a time by the Union Carbide Company at Niagara Falls is of quite different construction from the others. It is called the continuous type furnace and is shown in Fig. 3. It consists essentially of two slowly revolving concentric drums. The furnace makes about one third revolution per day. The outside plates are removable where the electrodes enter, and at the point where the sufficiently cooled carbide is broken up and taken out. At other points the plates hold the charge in place. The end plates are fixed. Only single-phase furnaces have thus far been mentioned, but large three-phase units of 7,000 h.p., 45,000 amps., 80 to 100 volts, are in operation in Europe.

The energy required to produce calcium carbide varies from 1.7 to 2 kw-hr. per pound.

Carborundum (SiC)

Carborundum is the name coined by its discoverer, Acheson, who in 1891 obtained what he thought was a compound of carbon and corundum (alumina) in an experiment in which he tried to dissolve carbon in and crystallize out diamonds from molten clay. The compound was in reality the carbide of silicon. Whereas originally it sold for many dollars an ounce, the price is now only a few cents a pound, and is used not only as an abrasive (most generally) but also as a refractory material, a paving material in approaches where traffic is heavy, a substitute for ferrosilicon in steel manufacture, etc.

The chemical reaction resulting in the formation of carborundum is generally represented to be:

$$SiO_2+3\,C=SiC+2\,CO$$

Tone, of the Carborundum Company, however, claims it to be formed in the following manner, from the silicon and the carbon monoxide vapors that are present:

$$3\,Si+2\,CO=2\,SiC+SiO_2$$

It probably is formed in varying degree by both reactions. In addition to the production

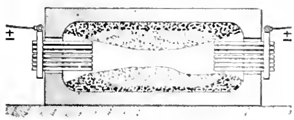


Fig. 4. Carborundum Furnace

of carborundum, monox (SiO), silicon, silocicon (Si_xC_yO) and graphite are formed under suitable conditions. All of these reactions are reversible.

$$SiO_2+2\,C=Si+2\,CO$$
$$SiC\quad=Si+C\text{ (graphite)}$$
$$SiO_2+C\quad=SiO+CO$$

The carborundum furnace charge is generally represented to be (in percentage parts by weight) thus:

Sand 52.2 per cent, coke 35.4 per cent, sawdust 10.6 per cent, salt 1.8 per cent. The sand is ground silica 99.5 per cent pure. The sawdust is used simply to give porosity to the charge in order to allow the carbon monoxide an opportunity to escape freely. The salt reacts with some of the impurities, forming volatile chlorides. Coke, or ground material from a previously used charge, is

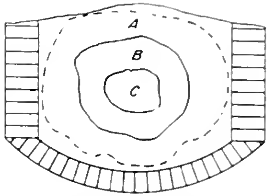


Fig. 5. Transverse Section of Carborundum Furnace Showing Relative Positions of Contents After Run
A, Uncrystalized carbide, or "carborundum fire-sand;" B, Carborundum; C, Carbon core.

used as a conducting core around which is packed the new charge. The core and charge are built up on a permanent foundation with replaceable sides of brick. Connection between core and electrodes is made by means of finely ground coke powder.

The standard furnace consumes some 2000 h.p. It requires about 250 volts at the start, but at the end of a run only 75 volts, when it takes 20,000 amperes. The temperature of the core may reach 3000 deg. C., but the zone in which the carborundum is formed (next to the core) should be between 1820 and 2220 deg. C., the temperatures at which the carbide begins to form and to decompose. The largest furnaces are 30 ft. long, and yield about 7½ tons of carborundum.

After a furnace run, the products of the reactions are found located in the order and approximate proportions as represented in Figs. 4 and 5. The carborundum is broken up, crushed, ground, purified, sized, and marketed as such, or manufactured into other forms

The siloxycon compounds are inferior to carborundum in quality, and do not find very extensive applications. They are formed in the furnace in the annular zone outside of the carborundum, where the temperature is not high enough for the formation of the carbide.

Silicon

While it is possible to manufacture silicon in a resistance furnace, as indicated in the carborundum furnace reactions given above, the method is not practiced commercially. Instead, a furnace of the arc type, using a charge of sand (SiO_2) and coke (C) is used. See Fig. 6.

$$SiO_2+2\,C=Si+2\,CO$$

The Carborundum Company taps a 650 to 900-lb. pig every few hours. This is broken to fragments under a huge iron drop weight,

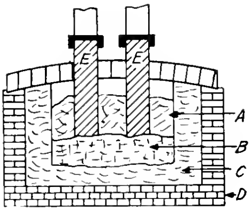


Fig. 6. Silicon Furnace
A, Charge of coke and sand; B, Silicon; C. Carbon lining; D, Firebrick; E, Electrodes.

with the further aid of sledge hammers. The grades made contain from 90 to 97 per cent Si. The furnace is built of fire brick with a carbon lining, and consumes about 1200 h.p.

The material is used mainly in the manufacture of steels, especially in the manufacture of the high silicon transformer steels.

Graphite

Graphite is made in a resistance furnace, very similar in form to the carborundum furnace. Acheson is responsible for the discovery of the graphitizing process, having first noticed the formation of the material from coke in the core of the carborundum furnace. Carborundum also forms graphite on decomposition at temperatures above 2220 deg. C. Acheson soon found that carborundum, or the carborundum furnace mixture, was not essential to the progress of the reaction. Carbon alone, in the form of large lumps even, could be converted, if only small quantities of a suitable catalytic substance were present. Thus, the present furnaces for graphitizing carbon in bulk possess a central core, surrounded by the charge mixture of granulated coke, or of anthracite, or of petroleum coke, together with the catalyzer, iron oxide. In some cases, the ash from the anthracite or coke will catalyze the reaction. At least 1 to 2 per cent of Fe_2O_3 is required.

A great proportion of the Acheson graphite is made into electrodes. These are graphitized from the molded mixtures of carbon binder and catalyzer, compressed to shape under high pressure. The carbon electrodes are loaded in a series of piles in the furnace, spaces between piles being filled with ground coke to increase the resistance.

In the conversion of the bulk graphite about 90 per cent of the charge is changed over. Of course, all of the charged electrodes are converted.

The furnaces compare in size with the carborundum furnaces, the largest consuming 1000 h.p. At the end of the run (20 to 24 hours) about 9000 amperes at 80 volts are passing.

The product resulting from the high temperature treatment is quite pure (99.9+per cent C.) due to the volatilization of the impurities. Pure, grit free, extremely finely divided graphite has been introduced to the trade as a very satisfactory lubricant under the names of "Aquadag" and "Oildag"—colloidal suspensions, respectively, in water and in oil. The influence which this industry has had upon other electrochemical industries in making available pure and perfect graphite electrodes is well known.

Alundum (Al_2O_3)

"Alundum," a trade name applied to fused alumina, is made from bauxite by a process and in a type of furnace exclusively operated by the Norton Company of Worcester, Mass. Like the identical natural product corundum, it is used as an abrasive. Its development has been phenomenal since the process was patented by Jacobs in 1900.

The furnaces which are located at Niagara Falls are rectangular and contain movable floors that are lowered as the fused alumina collects. The heat is obtained from a series of four arcs between as many pairs of electrodes. The electrodes are surrounded by the bauxite, previously dehydrated. Each furnace takes about 2500 amperes at 110 volts, producing about 7000 lb. of alundum per 24-hour day. The material finds application as an abrasive wherever carborundum is used. It is also used in crucible form as a refractory.

Fused Silica (SiO_2)

The manufacture of fused silica ware became possible only on the introduction of electric heat. Transparent ware is made by Heraeus, and translucent or vitrified silica ware by the Thermal Syndicate Company of England. The silica is generally fused in electrically heated graphite molds, or other suitable metallic molds. Temperatures of about 2000 deg. C. are required. The vitrified ware is now used extensively in the chemical industries.

Carbon Bisulphide (CS_2), a Distillation Product

The electrothermic manufacture of carbon bisulphide is referred to because it well demonstrates the advantages of electric heat, and because it employs a most ingenious furnace which was designed and patented by E. R. Taylor in 1899. The process and furnaces are still in operation at Penn Yan, N. Y., where the manufacture was first started. It is said that the original furnace

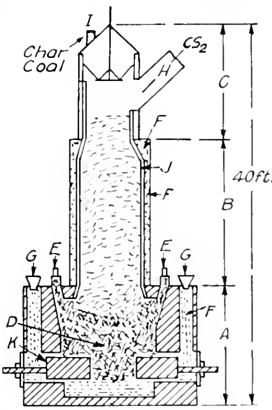


Fig. 7. Cross-section of the Taylor Carbon Bisulphide Furnace

A, Hearth; B, Shaft; C, Head; D, Charge of charcoal; E, Opening for feeding broken carbon to serve as conductor; F, Sulphur; H, Opening for conducting off carbon bisulphide gas; J, Annular space filled with sulphur; K, Carbon electrodes.

was operated for the first two and one half years with but one shut-down for cleaning. A cross-section of the furnace is shown in Fig. 7. It is 40 ft. high, and resembles somewhat an electric melting shaft furnace, with its hearth, shaft, and head.

The reaction consists in the union of sulphur (volatilized and highly heated by an electric arc) with incandescent coke, according to the equation:

$$C+2\ S=CS_2$$

The coke is fed in through the head of the furnace at *I* at such a rate as to keep the shaft *B* well filled. The sulphur is fed into the arc zone in molten condition, after being melted by waste heat of radiation in passing down the annular passages *F* outside both shaft and hearth. The CS_2 is cooled by heating the coke as it descends into the reaction zone, and is taken off through the furnace head at *H*, and condensed.

The heat is supplied by two-phase current, arcs playing between two pairs of carbon electrodes placed 90 deg. apart. The space around and above the electrodes is filled with pieces of graphite, broken bits of carbon, etc. (*D*), to protect the electrodes (*K*), which are consequently subjected to very little wear. As the furnace walls are gas-tight no CS_2 vapors escape. About 1000 amperes are supplied at 60 volts and 0.52 kw-hr. per pound of CS_2 is required.

Fixation of Atmospheric Nitrogen

According to good authority, considerably more than 3,000 technical articles dealing with the problem of nitrogen fixation from all points of view have appeared in English and foreign languages to date. In the same period, thousands of patents pertaining to the processes have appeared. The difficulty of discussing the subject in a very few words is thus at once evident. Only the best known, or commercially operated processes, will be mentioned.

The methods of fixation depending upon the direct oxidation of atmospheric nitrogen are carried out in three different types of arc furnaces, all of which are in commercial operation. While the Norwegian Eyde furnace is best known, the Schonherr furnace has found considerable favor. The third and less used furnace is the Pauling. Though the furnaces are all of different types, there is not great difference in the yield of NO gases obtained. The Schonherr furnace gives the highest concentration of NO, but the Eyde furnace gives a little higher output of NO per kw-hr. The electrode wear is very rapid in the Pauling furnace, and the slowest in the Eyde. The power factors are close to 70 per cent for all the furnaces.

Two other processes may be mentioned that are really chemical rather than electrochemical, although electric heat is used at points in each process, not because exceedingly high temperatures are required but because temperature control is essential. The Serpek process fixes nitrogen through inter-action with alumina and carbon The nitrogen comes from the air, the alumina from bauxite, and the carbon from coal which is heated with the bauxite to calcine it. The reaction temperature lies between 1800 and 1900 deg. C., and the reaction itself is:

$$Al_2O_3+3\ C+N_2=2\ Al\ N+C3\ O$$

The aluminum nitride is convertible into

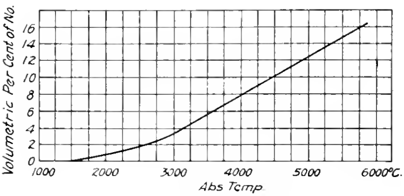


Fig. 8. Curve Showing Theoretical Concentration of *N O* in Air at Various Temperatures

ammonia through treatment with steam, and the ammonia may be converted into nitric acid.

The other process is the Haber, which causes nitrogen and hydrogen to unite directly through the agency of some catalytic agent, according to the reaction:

$$N_2+3\ H_2=2\ NH_3$$

Leland L. Summers gives an interesting comparison of power consumptions for the several processes for nitrogen fixation referred to:

	Per lb. of N
Direct oxidation of atmospheric N at 5 per cent efficiency	30.0 kw-hr.
Cyanamid process—carbide 66 per cent and cyanamid 99 per cent efficiency	7.5 kw-hr.
Serpek process	5.5 kw-hr.
Haber catalytic process	0.7 kw-hr.

The theoretical requirements of those processes that oxidize atmospheric nitrogen in high temperature arcs will now be referred to.

The Oxidation of Nitrogen

The reaction which results in the formation of *N O*, from *O* and *N*, is a reversible one, so that the concentration of the *N O* (which is small at best) is rigidly dependent upon the temperature, in accordance with the equilibrium law. Nernst and Jellinek have experimentally verified the theoretical calculations for *N O* concentrations in air at the various high temperatures that are represented in the curve of Fig. 8. Some of the results at the lower accessible experimental temperatures are here given:

Temp. C. Abs.	PER CENT *N O*	
	Observed	Calculated
1811	0.37	0.35
2033	0.64	0.67
2580	2.05	2.02
2675	2.23	2.35

At the equilibrium temperature the oxide is decomposed as rapidly as it is formed above the equilibrium concentration. Nernst and Jellinek have shown that if the oxide once formed can be removed rapidly enough and cooled to 1500 deg. C., further decomposition is slight. The commercial arc furnaces are, therefore, all designed to permit of the removal of the gases from the zone of high temperature as rapidly as possible. Thus a rapid movement of air through the arc is required, which increases the radiation and convection losses to such an extent that not only is the maximum temperature of the arc unattainable, but the efficiency of the process is very low, as was represented above.

Birkland-Eyde Furnace

This furnace, invented by Prof. Birkeland and Mr. Sam Eyde, of Norway, depends on the interaction of an alternating-current arc

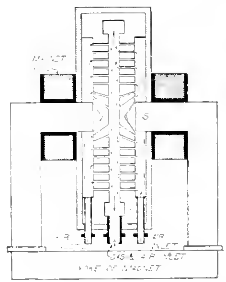


Fig. 9. Cross-section of Birkeland-Eyde Furnace

in a constant magnetic field. The furnace, as installed at Notodden, consists of a circular sheet-steel drum about 8 feet in diameter and 2 feet wide, lined with refractory firebrick, and having a disklike space in the center $6\frac{1}{2}$ feet diameter and $1\frac{1}{4}$ inches wide. Air is supplied at the center of the furnace by a blower, while a channel round the periphery of the disk space carries off the gases and unoxidized air, as shown in Fig. 9.

Two electrodes which are shown in Fig. 10, project into the center of the furnace and are approached to within about 1/3 inch. They are copper tubes, 2 inches diameter and 3/16 inch thick, and have water circulation to keep them cool.

Surrounding the points of the electrodes there is a magnetic field of about 4500 lines of force per square centimeter. Alternating current at 5000 volts and 50 periods per second is supplied to the electrodes, and direct current flows through the coils to produce the magnetic field.

When an arc is struck between the electrodes it is at once deflected in a direction perpendicular to the lines of force, and the necessity of having alternating current applied to the electrodes will be appreciated from the fact that with direct current the arc would be deflected to one side only. As each electrode is alternatively positive and negative, the arc is projected outward first to one side and then to the other, thus giving a disk of flame about 6 feet in diameter. The speed at which the arc moves outward is extremely rapid, and as the formation of a new arc is practically instantaneous, it appears to the eye as a sheet of flame.

When the extremities of the arc retire along the electrodes the arc increases in length, its resistance also increasing, until the tension is such that a new arc strikes between the points of the electrodes. The resistance of this short arc being smaller,

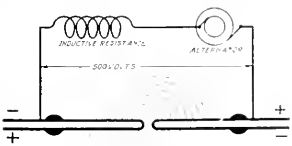


Fig. 10. Diagrammatical Sketch of Birkeland-Eyde Furnace showing Connections and Displacement of Semicircular Arcs

the tension of the electrodes suddenly sinks to a point that will not sustain the long arc, which is thus extinguished. Another arc starts, and so the process goes on.

An inductive resistance is a very necessary piece of apparatus to have in series with the arc, because its self-induction automatically effects a displacement of phase according to the currents flowing, thus enabling the arc to burn steadily.

A curious feature of the arc flame is that it is not quite concentric. When looked at through colored glasses the extremities of the arc appear like glowing spots upon the sides of the electrodes; on the positive electrode they are small and fairly close together, while on the negative electrode they are larger and farther apart. The reason for these spots appears to be that the arcs solder themselves, so

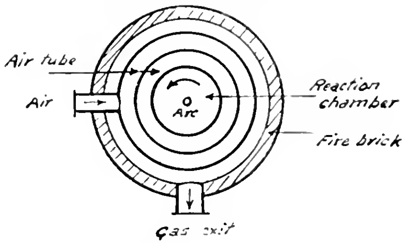


Fig. 11. Cross-section of Schonherr Furnace

to speak, to the electrodes, and the magnetic lines of force make the extremities of the arcs move along in leaps. For some reason not yet explained, the extremities of the arc cling more closely to the negative than to the positive electrode, and therefore the flame extends farther along the positive electrode than along the negative, as shown in Fig. 10.

When the flame is burning it emits a loud noise, from which the furnace attendant can judge of the number of arcs formed per second. The electrodes are changed and repaired every 300 hours, and the fireproof lining every fourth to sixth month. The temperature of the flame is about 3500 deg. C., and the temperature of the escaping gases is between 800 and 1000 deg. C.

The new furnaces at the Riukan works have a capacity of 4000 kilowatts.

Schonherr Furnace

This furnace consists of a long iron tube fixed vertically, through the center of which an arc 16 to 20 ft. long is maintained. Alternating current at 1200 volts is used, and each furnace takes 1000 h.p. Air blown through this tube with a whirling motion keeps the arc in the center. The electrode at the bottom consists of an iron rod which passes through a copper water-cooled tube. The iron rod is pushed upwards, as it burns away to ferric oxide, and fresh rods are screwed on as required, so that the process does not stop. At the top of the tube there is a water cooler, and it is inside here that the arc ends by striking across from the center to the side of the tube.

As will be seen from the arrows in Fig. 11, the incoming air passes through annular tubes, on each side of which there are the hot gases from the furnace. The air is thus heated to about 500 deg. C. before it reaches the arc. After passing through the arc where some of it is heated to about 3000

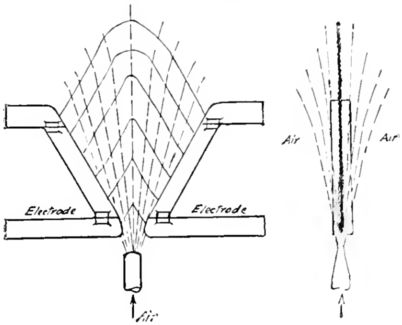


Fig. 12. Sketch showing Principle of Pauling Furnace

deg. C., it reaches the water cooler, where its temperature is then suddenly reduced. At this point there is a rapid mixing of the highly heated nitric oxide next to the arc, with the cooler air that is whirling past, and the gas becomes permanently fixed. The nitric oxide and air leave the top of the cooler at about 1200 deg. C., and pass away to a gas flue, common to all the furnaces, where the temperature is reduced to about 850 deg. C.

Pauling Furnace

This furnace consists of two hollow iron electrodes, arranged to form a V, which at the lowest point is about 4 centimeters across, as shown in Fig. 12. At this point there are two lighting knives which can be approached to within a few millimeters and are readily adjustable. The arc stripes across and runs up the diverging electrodes by reason of the natural convection currents and the repelling action of its own magnetic field, but principally because of a blast of heated air from an air duct immediately below. The arc diverges as it follows the shape of the electrodes, and it attains a length of about a yard. At each half period of the alternating current a fresh arc forms, so that the result is the equivalent of a triangular sheet of flame.

An important feature is that the wall which divides the two parts of the furnace is hollow, and gas and air which has been through the furnace previously and been cooled are blown through this central passage. As will be noticed from Fig. 12, this cool gas and air strikes into the top of the arc flame, and serves to cool the gases which have just been formed.

Nitric Acid

As carried out at Notodden, the method of making nitric acid is as follows: The nitric oxide gas and air pass from each furnace into two fireproof-lined gas-collecting pipes, about 6 feet in diameter, lined with fire brick. These pipes convey the gas to four steam boilers, the heat given off by the gases being used to raise steam for concentrating the products and for driving the air compressors for pumping acids, soda, etc. The gases then go through tubes in the evaporating tanks, after which the temperature is down to about 250 deg. C. The temperature is lowered still further, to 50 deg. C., by passing it through a number of aluminum tubes over which cold water is flowing. The gas then enters the oxidation tanks, which are large vertical iron cylinders, having acid-proof linings. Here it continues to take up oxygen to form nitrogen peroxide, the percentages being now about 98 per cent air and 2 per cent nitrogen peroxide.

The nitrogen peroxide is brought into contact with water to form nitric acid, in two series of four towers. These towers are built of granite and are filled with earthenware, this substance and the granite being chosen because they are not affected by acids.

The liquid trickles down through the quartz, and meeting the nitrogen peroxide gas, combines with it. The liquid moves from tower to tower in the opposite direction to the gas. Thus the fresh water enters at top of the fourth tower, it flows down through the interstices between the pieces of quartz and falls into a granite tank. From there it is pumped by compressed air to the top of the third tower, down which it trickles into another tank, and from which it is pumped to the top of the second tower, and so on.

When the liquid reaches the bottom of the first tower it contains about 40 per cent nitric acid.

The best result at Notodden has been 900 kilograms of nitric acid per kilowatt-year measured at the arc terminals and allowing for 100 per cent nitric acid.

Electric Furnaces for the Production of Steel and Ferro-alloys

By J. A. Seede

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This article is a natural sequel to the preceding one. The finest steels are made in the electric furnace, as are also the ferro-alloys discussed in Mr. Richard's article on page 751. Mr. Seede briefly reviews the fundamentals of high-grade steel manufacture, and gives a number of sound reasons to account for the superiority of the electric steel furnace over all other types. The article is concluded with descriptions and sketches of some modern designs of electric furnaces, and numerous wiring diagrams are included, showing the electrical connections in common use.—Editor.

GENERAL

A device for the transformation of electrical energy into heat with the intention of effecting various chemical and physical changes is called, within certain limits, an electric furnace. It must be understood, first of all, that the electric furnace is not primarily an electric device, but that it has a definite function, for example, in the case of the electric steel furnace, of taking certain materials in a raw or unfinished state and turning them into a finished product that has certain qualities that cannot be obtained, either in the same quantity or at the same price, in any other way. Although it has been known for many years that electrical energy can be transformed into heat, the electric furnace, as we know it, is a comparatively recent development, but already an indispensable factor in the manufacture of many products.

This is obvious when we consider the far-reaching commercial effect of such applications as the production of aluminum, calcium carbide, artificial graphite, carborundum and other artificial abrasives, etc. This list demonstrates that the electric furnace is a necessary element in our civilization. It is practically impossible to give in the space at our disposal a detailed description of all furnaces that have been used, much less those that have been proposed, and this article will deal only with the more common and important designs, especially those for melting and refining steel.

Construction

An electric furnace consists of a steel plate casing holding the refractory lining and mounted on rollers or trunnions when designed for tilting service, or on an ordinary foundation when of the stationary type.

The tilting furnace is generally supported on rollers, although other arrangements are used, such as supporting the furnace on trunnions and tilting about a point nearer the spout, this construction requiring very little movement of the ladle.

The method of supporting the electrodes varies somewhat, but in general consists of a water-cooled alloy holder supported on a structural steel arm or by wire ropes. Occasionally steel holders are used on small furnaces, as this permits of air cooling, and is reported to do away with the breakage occasionally experienced in alloy rings. Water-cooled rings are also used where the electrodes pass through the roof or walls, in order to reduce the temperature at points where high temperatures would mean rapid oxidation and electrode consumption.

While all tilting furnaces for melting and refining, and some stationary furnaces, are fitted with closed tops, a great many furnaces, especially for making ferro-alloys, are of the open top type. Inside of the circular casing is a brick lining which holds the stamped inner lining of fine material forming the hearth or bottom, and above the lining are the side walls. If a basic lining is used, the bricks are of magnesite (magnesium oxide), and the fine material of magnesite or dolomite (magnesite with varying percentages of lime, calcium oxide); or if an acid lining, the bricks and fine material will be of silica (silicon oxide). In all cases the roof is generally of silica brick, although other materials have been used with success, such as ordinary fire brick, carborundum brick, etc.

Types

All electric furnaces are of the arc type, resistance type, or a combination of these, and in all electric furnaces electrodes are required, with the exception of the induction furnace, in which the current is induced in the charge itself. This means that the induction furnace cannot be started with ordinary scrap, but must have a closed metallic circuit in the hearth, such as a ring of solid or molten metal. In the induction furnace, and most resistance furnaces, such as the graphite furnace, all the heat is generated by passing the current through the charge, but in certain cases the heat is generated in resistors or arcs external to the charge; for instance,

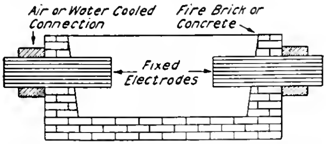


Fig. 1. Cross Section of Resistance Furnace Used in Making Graphite, Carborundum, etc. The current passes from one electrode through the charge to the other electrode

in resistance furnaces for various kinds of heat treatments, and the Stassano and Rennerfelt steel furnaces. In still other cases the heat is generated by current passing through arcs in contact with or buried in the charge, with some additional heat from current passing through the resistance of slag or charge; for example, practically all the other electric steel furnaces, and furnaces for making ferro-alloys, calcium carbide, etc.

In general, furnaces are of two classes, those used for smelting and those used for melting and refining; smelting furnaces being of the fixed or stationary type, while melting and refining furnaces are of the tilting type. Consequently, for the same capacity, smelting furnaces are cheaper to build and need not be maintained in such good physical condition as tilting furnaces.

Rating

The standard rating of a smelting furnace is based on a 24-hour continuous output, such as a 450-ton blast furnace, while melting and refining furnaces, such as open hearth, electric, Bessemer, and tropenas furnaces, are rated on holding capacity per heat, that is 5 tons, 50 tons, etc. Some manufacturers have attempted to rate their melting furnaces on a continuous period basis, with a resultant confusion between customer and furnace salesmen generally.

SMELTING FURNACES

Under this heading can be grouped those furnaces for making calcium and silicon carbides, ferro-alloys, (such as ferrotungsten, ferrosilicon, ferromanganese), phosphorus with its compounds, etc. The furnaces are of the open or closed type, depending partly on whether the product is in the gaseous form and is to be condensed, as in phosphorus or zinc production, or whether the gases are simply waste products and must be taken away as quickly as possible. Smelting furnaces may be either of the continuous or intermittent type, and in either case we may have a furnace where there is practically no lining except the raw material, the iron casing sometimes being artificially cooled by air blasts or jets of water.

Products

Some of the most important products used in the manufacture of steel, which are referred to constantly at present, are the various ferro-alloys, such as ferrotungsten and ferrochromium required in the manufacture of high-speed steel and armor plate, ferrosilicon and ferromanganese used in making ordinary steels. Theoretically, the process is very simple, requiring only the heating, by an electric arc, to a temperature approximating 1600 deg. C., of a mixture comprising a reducing agent such as coke or charcoal, a source of iron such as scrap steel or iron ore, and the oxide of the metal such as silica, which determines the character of the alloy.

The operation is started by placing a small amount of coke in the bottom from which to draw the arc, after which the charge is filled in around the electrodes until normal operating conditions are reached. At comparatively regular intervals the furnace is tapped and the

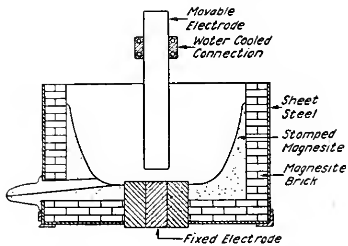


Fig. 2. Cross Section of Furnace Used in Making Ferro-alloys or Other Smelting Work, and Generally Referred to as Siemens Type. The current arcs from the upper electrode to the charge and then to the bottom electrode, and this arrangement may be used in single or polyphase operation

product allowed to flow out in a thin sheet for ease in breaking. The use of cast-iron borings, usually a drug on the market, has been suggested for this work, but they cannot be used, except very occasionally, on account of objectionable impurities.

Theory of Operation

It might be interesting to learn where the electric energy is used and to compare the theoretical energy with that required in practice, and for this purpose we will consider the manufacture of 50 per cent ferrosilicon. The total energy is the sum of that required to reduce the silica, plus the energy necessary to heat the iron and silicon to 1600 deg. C. and the carbon and oxygen to 1000 deg. C., minus the heat produced by oxidation of the coke. The reason that the carbon and oxygen are only heated to 1000 deg. C. is because they form carbon monoxide which escapes at approximately 1000 deg. C., giving up the amount of energy represented by the difference of temperature between this figure and 1600 deg. C. The chemical reaction is

$$\overset{28.3}{Si}\ \overset{32}{O_2} + \overset{24}{2C} = \overset{28.3}{Si} + \overset{56}{2CO}$$

In other words, 28.3 kg. of silicon combined with 32 kg. of oxygen react with 24 kg. of carbon to form 56 kg. of carbon monoxide, 28.3 kg. of silicon being liberated. The 28.3 kg. of silicon then combines with the same weight of iron to form the alloy. 28.3 kg. of silicon requires 180,000 cal. to reduce it from 50.3 kg. of quartz, and accordingly 455 kg. (1000 lb.) requires 2,890,000 cal. (3360 kw-hr.). The heat of combustion of 24 kg. of coke to CO = 58,400 cal., or 920,000 cal. (1070 kw-hr.) will be produced by the oxidation of the 386 kg. of coke required to produce 1000 pounds of silicon. This makes a net total of 1,970,000 cal. (2290 kw-hr.) for the chemical reaction.

For heating the silicon from 15 deg. C. to 1600 deg. C., assuming a specific heat of 0.21, requires 1585×455×0.21 = 151,000 cal. (176 kw-hr.) for the 455 kg. (1000 lb.). For heating the CO from 15 deg. C. to 1000 deg. C. (specific heat, 0.25 assumed), requires 900×985×0.25 = 221,000 cal. (257 kw-hr.). Summarizing we have:

	Cal.	Kw-hr.
For chemical reaction	2,890,000	3360
For heating the silicon	151,500	176
For heating and melting the iron	141,000	164
For heating the CO	221,000	257
Gross total	3,403,500	3957
Heat from carbon oxidation	920,000	1070
Net total	2,483,500	2887

In other words, if we take 455 kg. (1000 lb.) of iron, 810 kg. (1780 lb.) of quartz, 386 kg. (850 lb.) of coke, and add theoretically 2887 kw-hr., we will raise this material to a temperature of 1600 deg. C. and produce one ton of 50 per cent ferrosilicon and 900 kg. (1980 lb.), or 25,000 cubic feet of CO.

In practical operation there is a shrinkage of about 10 per cent, which brings the energy up to 3180 kw-hr.; and when we consider the radiation from the sides and top of the furnace, a furnace operator is doing very well if he maintains an average consumption of 6000 kw-hr. per net ton, while values of 7000 and 8000 kw-hr. are met, giving relative efficiencies of 53, 45.4 and 39.8 per cent respectively.

Fig. 3. Resistance Furnace in Operation, Making Special Carbides The flames show gases burning above contact area between electrodes and charge

RESISTANCE FURNACES

In resistance furnaces the charge, when cold, is usually a very poor conductor, and some method must be used to start the current, such as a conducting core, high voltage, or a combination of these. If the electrodes are fixed, voltage regulation is necessary to control the power input, for as the charge heats up the conductivity increases. There are various ways of accomplishing this result, such as the use of induction regulators or various arrangements of transformer taps; both methods sometimes being used. Although this regulation is sometimes accomplished on the low side, especially in smaller capacities, the preferred method is to carry the low voltage busses to the furnace in as direct and short a route as possible and

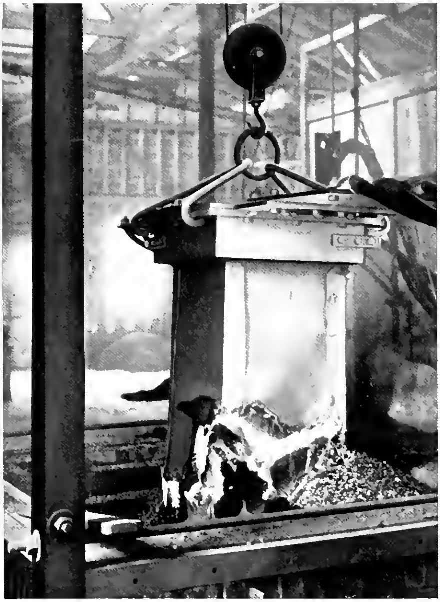


Fig. 4 Photograph taken shortly after 20-inch square carbon electrode had broken on a single-phase Ferro-silicon Furnace

to do all the switching on the high tension side. For this switching one of the latest arrangements, which is already in operation, is the motor-operated multipole oil switch which seems to offer a maximum of reliability and safety with a minimum of complication.

MELTING AND REFINING FURNACES

Melting and refining furnaces are used principally in the manufacture of various steels and are all practically of the same construction, the main difference being in the electrical connections and disposition of the electrodes.

Until electric furnaces were introduced the melting and refining of high-grade steel was practically all done in crucibles holding 80 to 100 pounds, these crucibles being made of a special clay and flake graphite, considerable care and experience being necessary to make a reliable product. The short life of these crucibles, which is independent of the amount of metal charged, makes it necessary to pack them with carefully selected materials of small dimensions, since with careless packing and low space factor the crucible cost per ton of steel may be greatly increased.

CRUCIBLE FURNACES

Prior to 1914, when the crucible maker could obtain the best materials at competitive prices, it was not unusual to use crucibles five or six times, which would bring the cost of crucibles per ton of steel down to $10 or $15. The situation at present, with crucibles of such poor quality that they seldom last more than two heats and cost 200 per cent above normal, brings the cost per ton to approximately $100. The crucibles are closed, and although they are sometimes opened for stirring, practically no refining can be done; and as the metal absorbs carbon from the crucible in varying amounts, considerable experience is required to offset the results of using varying percentages of new and old crucibles, different kinds of scraps, and different kinds of product On the other hand the method of melting out of contact with the air with metal motionless, thus obtaining practically ideal conditions, has earned for this steel a well-deserved reputation for high quality.

This is in direct contrast to the furnace ordinarily used for casting metal, such as small tropenas and similar converters, in which the metal is violently agitated all through the process, preventing the gases and slag from settling out, the result being the production of so-called "wild steel," which causes porous and defective metal.

ELECTRIC STEEL FURNACES

Compared to these processes the electric furnace combines the practically motionless bath conditions and atmosphere of the crucible furnace with the possibility of refining and controlling the composition of the steel, which factors in combination are not found in any other furnace and which enable the production of the highest class product in quantities large enough to be considered on a commercial scale.

The reducing atmosphere of the electric steel furnace enables the operator to adjust his conditions to eliminate phosphorus and sulphur as desired, and instead of finding it necessary to use very high-class materials of small and regular size, as in crucible practice, he can use cheaper materials of any commercial form within reasonable limits.

The metal from the electric furnace is extremely quiet, just as much so as well-killed steel from crucibles; and this property, together with its peculiar toughness, is ascribed to the elimination of gases and other deleterious substances through refining the metal in a reducing atmosphere.

It is claimed that electric furnace steel is considerably tougher and has greater resistance to wear than other steel of the same composition, and that it has an unusually high elastic limit and contraction of area, and that when the process has been properly conducted practically all defects are eliminated. It is also claimed that it forges better and stands higher forging heat than crucible steel, and that in general, especially from a cost basis, it is superior to any other metal. The quality of this steel is indicated by the fact that, so far as is known and contrary to general experience with other steels, no rail made from electric furnace steel has ever been broken in service. The importance of such a material with regard to continuity of service and safety to passengers can hardly be over-estimated.

Some Advantages of the Electric Steel Furnace

1. Better steel at lower cost than crucible steel.
2. Adaptability—tool steel today, casting steel tomorrow.
3. Varying cycle—successive heats today, one or no heats tomorrow.
4. A simple arrangement of standardized equipment requiring comparatively small floor space.
5. Comparatively low installation and maintenance costs.
6. A simple and effective control equipment.
7. Ease and certainty of control with resultant high-class product.
8. No danger from explosions or shocks.
9. Reducing atmosphere of furnace enables charge to be held almost indefinitely without change in analysis.
10. These equipments can no longer be considered experimental.
11. From the power company's standpoint, a balanced 3-phase high power-factor load, with load factor superior to many motor loads.
12. From the customer's standpoint the additional power consumption enables him to purchase power at lower rates for his whole plant, and if the plant load is large enough and contracts are so drawn, enables him to fill in the difference between the peak and average loads with special work.

Operation

As soon as the steel and slag from the previous heat have been drawn from the furnace a careful inspection is made of the lining, and any holes filled with magnesite, dolomite, or silica, as the case may be.

In certain practice with basic linings, a small amount of lining material is scattered over the bottom of the furnace, which is followed by a layer of scrap steel, then some lime, more scrap, and so on until as much metal is charged as can reasonably go into the furnace. The purpose of scattering the lime through the raw material is to enable it to assist in purifying the metal, as the latter is melting, and the lime works through the charge to the surface, forming the slag.

If the metal is known to be too high in silicon or carbon, some iron ore is added, preferably near the bottom, in order to temporarily agitate the metal, in which case it will combine quickly with the undesirable elements, which will pass off as gas or else form part of the slag.

In the largest furnaces the cylinder of metal directly under each electrode may not be enough to form a pool beneath the electrode, in which case the electrodes are withdrawn from the metal, additional scrap thrown into these holes, and the process repeated.

Where graphite electrodes are used, this process may take place three or four times before there is sufficient metal beneath the electrodes to prevent serious damage to the bottom of the furnace. In drawing the arc it is a good practice to lower one electrode onto the metal and then bring down the two other electrodes (in the case of a 3-phase furnace) and draw arcs to the metal until reasonably flat spots are developed, after which the automatic control is allowed to take the furnace in hand, the operator maintaining a close watch for half an hour to see that the arc does not come too near the bottom and destroy part of the lining.

This is the period that is hardest on the electrical apparatus and is the time when we believe that the extra high voltage and reactance may be of great service. It is obvious that as the electrodes bore their way through the charge considerably more of the scrap will be melted if a long arc is used which will radiate energy in all directions.

In starting the arc a few shovels of lime thrown around the electrodes assist in holding the metal under the electrodes and in maintaining a steady arc. As soon as they have gone down sufficiently to form a pool the remainder of the charge begins to melt and the electrodes begin to climb out of the holes they have bored into. Shortly after this happens we have the furnace partly filled with molten metal in which are floating pieces of unmelted scrap and floating islands of lime and slag. During the melting full power is used until too much heat is radiated to the roof and side walls, when the power is reduced to complete the process.

In many cases the entire charge is made at first, and if so the process continues until the charge is entirely melted, when the necessary additions are made and the steel is poured into a ladle, where it is transferred to ingot molds when it is to be made into fabricated steel, or into ordinary molds when it is to be used for castings.

If any special refining is to be done, ordinarily two slags are used, the first one of an oxidizing nature to remove phosphorus and the second of a reducing nature to remove sulphur and any oxides that may be present.

When charging with hot metal, as contrasted to the cold charging referred to above, the operation is simply a refining process and considerably less power is used, the amount being determined by the temperature of the charge.

From the standpoint of production, the electric furnace is immeasurably superior to other furnaces, especially the crucible furnace, when we consider the terrific discomfort of the operator when handling white hot crucibles.

The electric furnace is especially suited for small plants, as a very irregular cycle can be followed, such as complete shutdown for several days, then as many heats as production calls for—a procedure that would soon wreck the lining of an ordinary furnace and possibly the furnace structure itself.

Costs of Electric Steel

In making ordinary steel the following figures may be taken as a fair average during ordinary times.

Material	Cost Per Ton
Energy 600 kw-hr. at 1 c.	$6.00
Electrodes, 30 lb. at $5\frac{1}{2}$ c.	1.65
Refractories (roof, wall and bottom)	.80
Slag	.50
Alloy additions	.80
Scrap $22 per ton	22.00
Labor	1.70
Overhead	1.20
Total per ton of molten steel in the ladle	$34.65

In making castings approximately 60 per cent of the metal will be recovered, which gives a figure of $57.75 per ton, to which must be added the customary molding charge, which would probably bring the cost well over $120, or $0.06 per pound.

Electric Energy

The value of 600 kw-hr. is sometimes considerably lowered in single heats and again is considerably exceeded in others, so that it is a fair average of good practice. The figure of $0.01 per kw-hr. is rather higher than that which can be obtained from the large central stations, but even at this figure it is not a very large factor, being 17.3 per cent of the total. This tabulation gives a good idea of the relatively unimportant part of the electric power cost, and shows how needlessly the public is concerned in regard to the high cost of electric heat in making steel.

Electrodes

The electrode cost is always a subject of great controversy, and advertisements state that heats are made with electrode consumption as low as five pounds per ton. It is needless to say that such figures take no account of breakage which must be met occasionally, and a fairer value is probably around the figure given above.

The electrode consumption is greatly affected by the way in which air is kept out and the gases prevented from passing out around the electrodes. It is also affected by the kind of steel being made, the gases that are given off, and the way in which the melter handles the furnace, that is, whether he pushes everything to the limit or uses the equipment in a reasonable way.

Refractories

The item of refractories depends upon the kind of metal being made, temperature of furnace, and the cycle in which the furnace is operated, an intermittent cycle being very much harder on the furnace than continuous operation.

Slag and Additions

The magnitude of these items depends upon the quality of the scrap and the kind of metal being produced.

Scrap

The question of scrap is a very important one, and is also affected by the product. Some furnaces can be found where expensive scrap is being used, but where much cheaper scrap would operate just as well, if not better; while in other places we find operators using the cheapest kind of scrap and attempting to produce high quality materials, with results that can be easily foreseen.

A statement that has undoubtedly done considerable harm to the electric furnace and that has been advertised a great deal, is that electric furnaces can take the poorest kind of scrap and make the very best product. While this statement is theoretically true, such treatment takes a long time, is destructive to the lining and electrodes, and otherwise is a very poor proposition from a commercial standpoint, and the unmodified statement should never be made.

Electrodes

The electrodes are made of carbon or graphite, the carbon electrodes being made of anthracite coal, petroleum, coke and other materials which are carefully chosen and mixed to produce a material that will withstand the severe service required.

Practically all electrodes are now circular in section and arranged with screw connecting pieces so they can be entirely used up, in this way saving the 25 to 50 per cent of electrode heretofore wasted. The electrode consumption varies from 20 to 50 lb. per ton of steel, and the price varies from 3½ cents for carbon electrodes up to 16 cents per pound for graphite electrodes, the price depending on the size and general market conditions. Carbon electrodes can be purchased in standard sizes up to 24 in. in diameter, and graphite electrodes up to 12 in. in diameter.

When putting in new electrode sections it is necessary to make the contact as perfect as possible, and extra precautions must be taken in the case of carbon electrodes. A fairly thick paste of flake graphite and oil, pitch or molasses, according to the opinion of the operator, is coated over the screw threads and the parts screwed together tightly. As the electrode becomes heated this forms a joint that is so highly conductive as to differ very little from any other section of the electrode.

Lining

There are two ways of baking in the lining of electric furnaces, one being the old method of mixing the fine calcined refractory material with about 12 per cent of tar, all materials being hot, and then stamping it into the finished shape and distilling out the surplus tar as completely as possible by means of comparatively low temperature heat, such as coke or wood fire. It is advisable to keep the atmosphere in the furnace neutral or slightly reducing in order to prevent burning the tar, which would result in a lining having no strength.

The alternative is a later method which consists in putting in a number of comparatively thin layers of lining material and then sintering them individually in place by means of high temperature heat, usually obtained by putting in a T of scrap electrodes and drawing arcs from the main electrodes to the three ends of the scrap electrodes. This gives a furnace bottom that is much superior to the other arrangement and is a comparatively simple process after it is once started, although it sometimes results in severe electrode breakage, especially when the furnace crew is new at the business.

TYPES OF STEEL FURNACES

Heroult Furnace

This furnace was originally developed in the single-phase type, having two electrodes, the current arcing from one electrode to the charge through the metal and up to the other electrode. The single-phase furnace has practically been abandoned except for small experimental equipments, and all commercial furnaces from one ton up are now of the 3-phase, 3-electrode type, and in the largest capacities six electrodes have been considered.

The furnace is usually provided with an automatic controlling equipment which keeps the current balanced in all phases and under normal conditions the power-factor of the furnace equipment is approximately 90 per cent. This means a combined reactance of 43.6 per cent which will give 229 per cent of full load current on sustained short circuit with primary potential maintained. This reactance value includes the reactance of the transformer and all the secondary leads.

The reactance of the secondary leads is comparatively low in the smaller sizes and

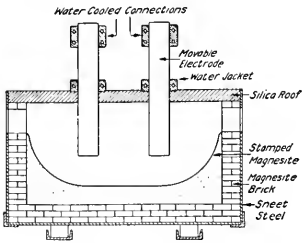


Fig. 6. Cross Section of Single-phase Furnace. Current arcs from one electrode to bath and up to other electrode

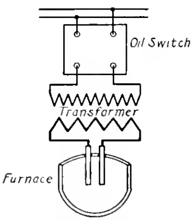


Fig. 7. Connection Diagram of Single-phase Furnace

considerable reactance value should be added in the one and two-ton equipments so as to prevent heavy surges when starting with the cold charge. As the reactance of the secondary circuits increases in the larger furnaces and the current also increases rapidly, we have an accumulative effect which is in the wrong direction. This means that the inherent reactance of the larger transformers should be reduced, and this is furthermore affected by the power circuit conditions which in some cases may be very poor, such as in certain installations around Pittsburgh where the Public Service regulations permit a 20 per cent variation and occasionally the voltage may drop 30 or 40 per cent. However, the low-voltage leads should be interlaced where possible to keep this component of the reactance low and if additional reactance is required, it can be easily installed later. This additional controllable reactance is useful in assisting to protect the transformers, electrodes, and installation generally.

It might be stated that a standard high-grade transformer does not require additional reactance for protective purposes beyond the 5 per cent ordinarily found. Any one interested in promoting the welfare of the manufacturer, power company, and customer, realizes that upon the limitation of current surges, within reasonable limits

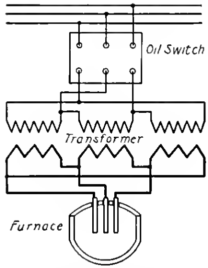


Fig. 8. Connection Diagram of 3-phase Heroult Furnace, Both Transformer Windings Being Connected Delta

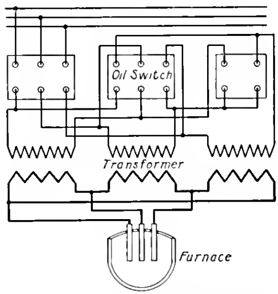


Fig. 9. Connection Diagram of 3-phase Furnace Arranged for Variable Voltage Operation by Means of Changing High-voltage Connections. The high melting voltage is obtained by connecting high-voltage windings delta and the low refining voltage by connecting them Y

consistent with energy input to the furnace and fair power-factor, depends the cost of power, the continuity of service upkeep, and reliability of electrical apparatus, and the general interest of all concerned in pushing this class of business.

Interlacing of busses also permits of running higher current densities, thus decreasing cost and complication of secondary copper. Another case where external reactance may be advantageous is in connection with installation where a higher voltage is used for melting, 100 volts being used for completing the melting and refining. In this case a sufficient amount of inherent reactance to protect the transformer on the high-voltage point would be excessive during refining, and there is no way of designing the transformer which will eliminate this trouble. It is obvious that the reactance of the secondary circuits will vary considerably, depending upon the arrangement of the leads and the disposition of the furnace and the transformers.

The question of the amount of reactance to use in the transformer is complicated by such considerations as line regulation and requirements of the power company in regard to overloads affecting the rate and customers. The amount of reactance is also varied by the conditions in the furnace at starting and after the charge is melted.

In the case of a standard 6-ton furnace having 1500-kv-a. transformer capacity we will be trying to force 8670 amperes through six tons of magnetic material, and it is obvious that the reactive drop will be very high and the power-factor correspondingly low. The question of reactance is also affected by the opinion the customer may have obtained in regard to power-factor from his talks with salesmen, and he will sometimes believe that a power-factor of 98 per cent will be of great benefit, while in reality a lower power-factor would be better in giving him more stable conditions, and the resultant decrease in capacity will affect him very slightly.

The amount of power consumed per ton of steel varies with the kind of steel produced, but in the single slag production of casting metal the average kilowatt-hour consumption during normal conditions, starting with cold charge, will be approximately 600 kilowatt-hours in the 6-ton size. In the smaller furnaces this figure may be exceeded.

In operating this furnace, as well as other furnaces where the current arcs between the electrode and the bath, it is well known that when starting with cold scrap the magnetizing effect of the charge has a strong choking effect on the current, lowering the power-factor, and diminishing the amount of power that can be forced into the furnace. This is a serious matter, as the melting period is usually the longest part of the cycle, and to overcome this difficulty it has been proposed to run the first part of the cycle with increased voltage. One of the simplest ways of accomplishing this is to switch the high-

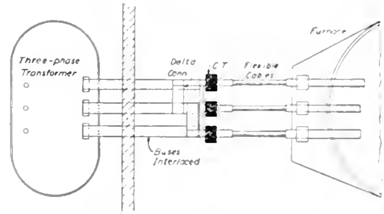


Fig. 10. Plan of Best Arrangement of Connections Between Transformers and Furnace. The interlaced busses give reduced reactance and heating, thus permitting of economizing in the amount of copper installed

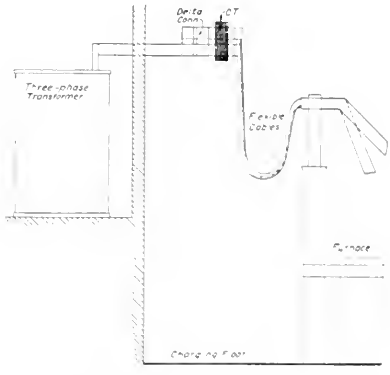


Fig. 11 Elevation of Most Approved Arrangement for Connecting Transformers to Furnace The busses are carried in practically a straight line and considerable saving is effected thereby

voltage winding to Y for starting the arc, and after obtaining good working conditions with 100 volts between electrodes, to connect high voltage winding to delta, electrode voltage 173, until the charge is practically molten, when the connections may be changed to give 100 volts to complete the refining.

The arc will be somewhat longer when using the high voltage, and as there is a tendency for the electrodes to bury themselves in the charge, this will permit of practically all the heat being absorbed by the metal.

in this way giving a rapid melt. Experience indicates that this range may be excessive and that probably it will be better to limit the variation to some smaller amount, as from 100 to 135 volts or possibly 150 volts.

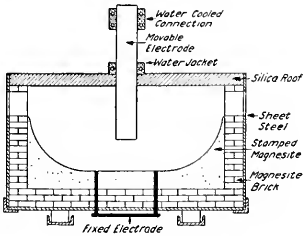


Fig. 12. Cross Section of Steel Furnace of the Bottom Electrode Type. The current arcs from the electrode to the metal and thence through the bottom electrode. This arrangement can be used for polyphase work if desired

Girod Furnace

This furnace is usually of the single-phase type, having one or more upper electrodes and bottom electrode, consisting of a number of steel bars embedded in the lining, usually air-cooled, but in the largest sizes water-cooled.

Those who favor bottom electrodes state that their use prevents chilling of the metal and the formation of skulls, and also imparts motion to the metal which assists in melting and refining.

As far as we know, there is only one polyphase furnace of the Girod type in this country, that being a 3-electrode, 10-ton furnace. The transformers are connected in Y with one leg reversed, which is practically the same as three single-phase furnaces in one casing, and all the current passes through the bottom electrode. These transformers are each rated 700 kv-a., with taps for either 65 or 80 volts.

Snyder Furnace

This furnace uses bottom electrodes and a high voltage, the voltage being normally 220 volts on open circuit with an external or internal reactance to give 160 volts at full load. On account of the high voltage the furnace is operated as a straight melting furnace and practically no refining is done. When refining, it is necessary to cut the voltage approximately in half. All Snyder furnaces are regulated by hand and it is claimed that the high reactance gives a practically constant current characteristic so that very little regulation is required.

The manufacturers have recently started the exploitation of a design using a 3-wire, 2-phase connection with one bottom and two upper electrodes, and employing standard type transformers.

Gronwall Furnace

This furnace is somewhat similar to the Girod furnace, with the exception that the upper electrodes are connected to the outside leads of a 2-phase, 3-wire connection, and the bottom electrode to the neutral. In small furnaces two upper electrodes are used, and in capacities of five tons and above four electrodes are used. Several large furnaces of this design have been in operation for some time, and are reported to be operating successfully. This furnaces have four upper electrodes and four single-phase oil-cooled transformers which permit of a variety of electrical connections in order to produce the best results.

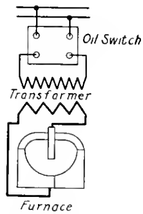


Fig. 13. Connection Diagram of the Single-phase Bottom Electrode Equipments

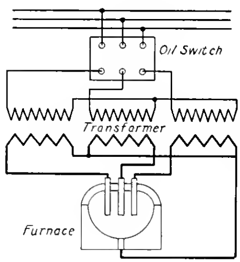


Fig. 14. Connect on Diagram of 3-phase Girod Furnace. One of the phases is reversed, in this way giving a 60 deg. Y connection, which causes practically all of the current to pass through the bottom electrode

Rennerfelt Furnaces

Where practically all other furnaces are circular in shape, the hearth of this furnace is rectangular, the whole furnace having the appearance of a horizontal cylinder. There are no bottom electrodes, all being situated above the metal and movable, each set having one vertical and two horizontal members. The two arcs between the side electrodes and the middle electrode combine to blow down in a blast of intense heat on the charge. A number of these furnaces have been sold in three tons capacity and below, and only two furnaces have been sold over four tons capacity, these being of the 6-ton size, and taking 1600 kw. each through six electrodes.

Rennerfelt has standardized in circuit with each electrode the use of a reactance with two coils having voltage drops of 10 and 20 volts respectively. As these reactances must be located some distance from the furnace, some kind of a remote control switch, such as a solenoid operated switch, is necessary to short-circuit them when they are to be taken out of circuit, and as the current might be high even in small furnaces it is obvious that this might mean a switch that is expensive and difficult to install and maintain. Reactance has been developed for this purpose which uses short-circuit coils having the same capacity, but with a considerably higher voltage which permits using standard contactors and accordingly reducing the short-circuiting to a simple control proposition.

Under these conditions the reactance may be located at the most advantageous point to reduce the amount of secondary copper and make the connection between the transformer and the furnace as short as possible. As the middle electrode must be adjusted to a certain fixed position automatic control is not feasible for this electrode, but can be used to advantage on the side electrodes.

Nathusius Furnace

This furnace may have two or three upper movable electrodes and the same number of bottom fixed electrodes, depending upon whether single-phase or three-phase power is used. By means of an auto-transformer connection between the upper electrodes, lower electrodes, and bath, the operator can heat the top or bottom of the charge independently, or at the same time, as he desires.

The underlying thought in the development of this furnace was probably due to the idea of hastening the melting and refining actions by thoroughly mixing the metal and in keeping the charge in motion as much as possible.

Stassano Furnace

In his brilliant experiments in high temperature work, Moissan used many

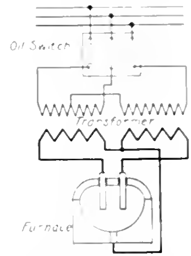


Fig. 15. Connection Diagram of the 2-phase Bottom Electrode Furnace. All of the current from the movable electrodes passes through the bottom electrode

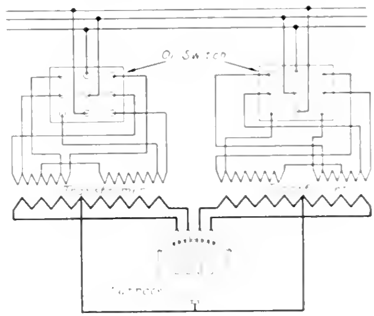


Fig. 16. Connection Diagram of 4-electrode Gronwell Furnace Used in Larger Capacities.

arrangements of electrodes, perhaps the most characteristic being a crucible into which two electrodes projected horizontally, and the heat from the arc above the metal raised the temperature of the furnace by radiation. The Stassano furnace is a variation of this equipment, in which 3-phase power is used on three electrodes. A number of these furnaces operated for a time in Italy with considerable success, but the operation was later discontinued, apparently due to several causes. A few of these furnaces have been tried in this country but practically all have been discontinued, although the quality of steel produced was said to be equal to the best.

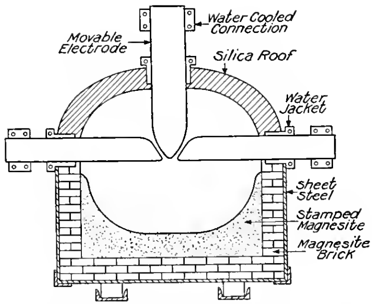


Fig. 17. Cross Section of Rennerfelt Furnace. The upper electrode is connected to the neutral of the 3-wire, 2-phase system and the two arcs combine in a flame that is projected downwards with great intensity

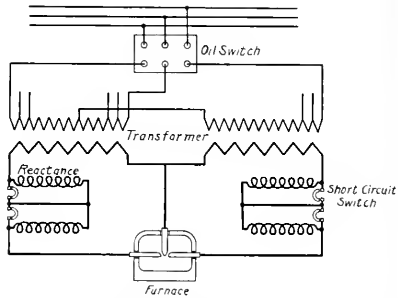


Fig. 18. Connection Diagram of 3-electrode Rennerfelt Furnace showing reactances which are connected in circuit at starting and afterwards cut out when the proper furnace conditions are reached

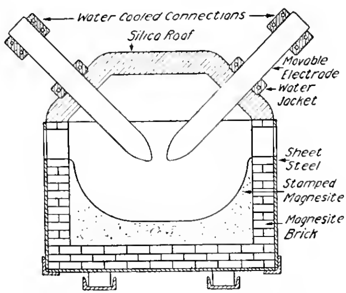


Fig. 19. Cross Section of Single-phase Stassano Furnace. Current arcs between electrodes and bath is heated by radiation

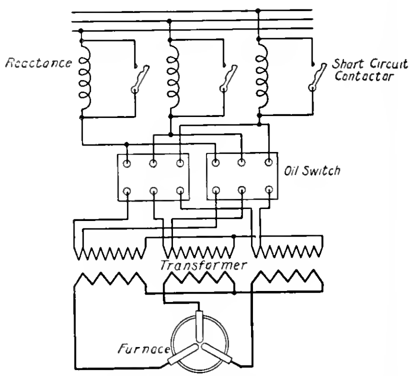


Fig. 20. Connection Diagram for 3-phase Stassano Furnace. Provision is made to use high-voltage at starting, at which time a reactance can be connected in circuit

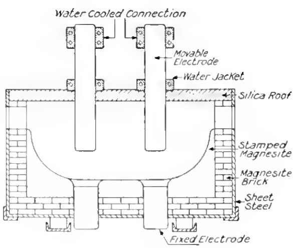


Fig. 21. Cross Section of Single-phase Nathusius Furnace

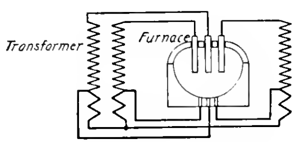


Fig. 22. Connection Diagram of 3-phase Nathusius Furnace

Greaves-Etchells Furnace

This is a type of furnace recently brought out in England, and consists of a standard hearth and tilting arrangements provided with two upper movable electrodes in the small sizes, and four, or possibly some higher multiple of two, electrodes in larger sizes, with lining acting as bottom electrode.

This furnace is designed for use with 3-phase power, three or six transformers being used, connected in a modified "Y."

Several furnaces of six tons and three tons capacity are in successful operation, and in a short time this number will be considerably increased.

Booth-Hall Furnace

This furnace normally operates with two upper electrodes and one bottom electrode, supplied with power from a 2-phase, 3-wire circuit, and is distinguished from other furnaces by the use of an auxiliary upper electrode for use during a short time at starting. This electrode is virtually connected in multiple with the bottom electrode. A number of these furnaces are stated to be in successful operation.

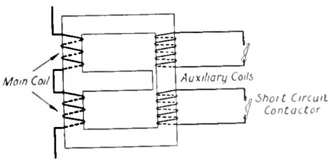


Fig. 23. Connection Diagram of Improved Reactance Which is Shown in Fig. 24

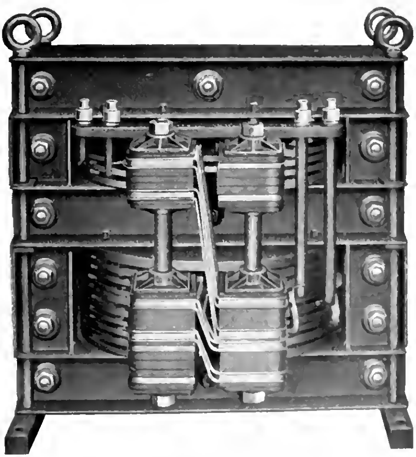


Fig. 24. Improved Reactance for Use With Electric Furnaces where short circuiting is done by means of high voltage, low current coils, in this way using standard contactors

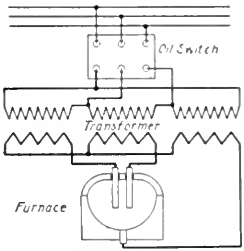


Fig. 25. Connection Diagram of Greaves-Etchells Furnace. Current arcs from two movable electrodes to bath and thence to lower electrode

Ludlum Furnace

This furnace has three upper electrodes supplied with power from a 3-phase, delta-connected circuit, and the normal operation is to have the middle electrode in contact with the charge, with practically all the resultant voltage drop on the outer electrodes. The three electrodes are arranged in a straight line, in this way giving the furnace a somewhat different appearance from other furnaces using three upper electrodes.

A number of these furnaces of 5-ton and 10-ton capacity are reported to be in successful operation.

Moore Furnace

The unusual feature of this furnace seems to be the use of various transformer connections by means of which different electrical characteristics are obtained at different parts of the cycle. The furnace takes 3-phase power through three electrodes and seems to be giving considerable success, especially in the Middle West.

Vom Baur

This furnace has three upper electrodes arranged in a straight line and is supplied with power from a 2-phase, 3-wire circuit, the neutral being connected to the middle electrode, which is normally somewhat larger than the outside electrodes because of the increased current. Other novel features are reported to be in use, and several of these furnaces which are soon to be in operation should give interesting reports.

Induction Furnace

The theory of this furnace is to generate the heat by passing current through the metal, and the idea of eliminating electrode consumption and reducing roof troubles by generating the heat underneath the slag instead of in and above the slag is very attractive. As no electrodes are used the roof can be built close to the metal, in this way diminishing the radiating surface, cutting down cost and heat capacity of lining, and greatly reducing the up-keep of this part of the furnace, which is ordinarily most difficult to maintain in good condition.

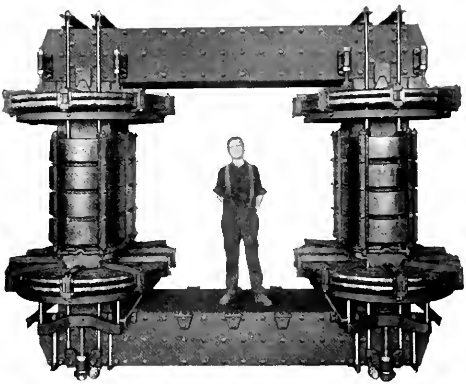


Fig. 26. Core, Coils and Coil Supports of 20-ton Single-phase Induction Furnace Taking 4000 kv-a. 50 Per Cent P-F. from Single-phase 5-cycle Generator

This furnace has a ring-shaped hearth built around the core and the primary winding, which, when filled with metal, forms the secondary of a transformer. It might be thought that an arrangement involving a bath of molten steel at 1500 deg. C. or higher, not more than 18 inches away from the winding carrying 2000 to 5000 volts, is very dangerous, and that extraordinary precautions would have to be taken to keep the coils cool; but it has been found that this can be taken care of by means of an air blast in the large sizes or by using copper tubes cooled by water flowing through them as windings in the smaller furnaces.

Due to the interaction between the heavy current in the bath and the flux, there is a rapid movement of the metal in a radial direction which tends to keep the temperature constant and assists in melting. The direction of flow is across the top of the channel to the inside, down the inner edge, and up on the outside edge. This motion is so strong that the difference in level from the outside to the inside, with a channel 12 in. wide, may be 1 in. or more.

Conclusion

It must be understood that an article of this nature must necessarily be somewhat incomplete and it is expected that a supplementary article will be published at a later date. Electrical furnaces are developing along many different lines, and as the applications are constantly increasing it is necessary that the subject be referred to frequently in order to keep abreast with developments, especially in such applications as deal with the steel and allied industries, which are of the highest importance.

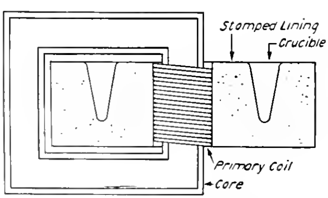


Fig. 27. Cross Section in Vertical Plane of Single-phase Single-ring Induction Furnace. Current is induced in metal held in ring shaped crucible

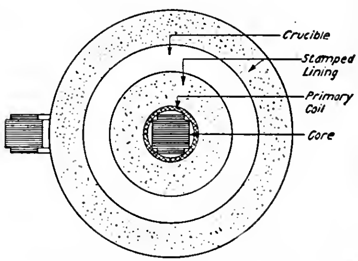


Fig. 28. Cross Section in Horizontal Plane of Single-phase Single-ring Induction Furnace

Electrodes for Electric Furnaces: Their Manufacture, Properties, and Utilization*

PART II

By Jean Escard

Civil Engineer, France

Part I of this article published in our October issue described the raw materials from which the furnace electrodes are manufactured, the processes of manufacture, and the physical and chemical characteristics. This installment considers the form, dimensions, grouping, and composition of the electrodes and their arrangement in the various types of furnaces; the life, wear, and protection of electrodes, and electrode holders, cooling systems, and methods of attaching the connections. The article is concluded with a short description of some of the less common forms of electrodes, such as the tubular electrode used in the Birkeland-Eyde and Pauling furnaces, composite electrodes (metal and graphite), and hearth electrodes.—Editor.

Form, Dimensions, Grouping, and Position in the Furnaces

The form of electrodes is either circular, square, or rectangular, the exact shape as well as the length varying with the application. The section is governed by the nature of the furnaces and the means at the disposal of the manufacturer. Large sections simplify operations, as then only a limited number of electrodes are necessary; but mechanical strength is lessened and the weight of each unit is liable to become excessive. Furthermore, in case of breakage it would be necessary to extract from the molten bath very heavy pieces of the broken electrode; as a consequence a whole furnace charge is liable to be lost by cooling, or in the case of steel by carbonization.

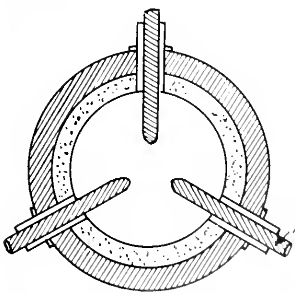


Fig. 5. Cylindrical Electrodes of Small Diameter (80 mm.) (3.15 in.) Used in a Three-phase Stassano Furnace

The employment of a greater number of small electrodes offers the advantage that the density of the current per unit can be increased, but the necessity of maintaining a certain distance between electrodes requires a reduction of the total section, and this results in lower daily production. When this plan is followed the section of each electrode does not go beyond 8 to 10 cm. (3 to 4 in.), and the electrodes are arranged in rows: for example, in the manufacture of aluminum four rows of 8 or 9 electrodes each are used, and a total number per furnace vat of 32 or 36, with a total current-carrying surface of 0.256 or 0.288 sq. meter (400 to 450 sq. in.). Carbons having sides of 25 cm. (10 in.) are arranged in two rows of five each.

At Trollhaetten (Sweden) the furnaces used for direct reduction of iron ores are of the two-phase type and four current-supplying electrodes are provided. Their section is square with 66 cm. (26 in.) sides, but in reality each electrode is composed of four parts placed side by side, each having 33 cm. (13 in.) sides. Their angle of inclination from the horizontal is 65 degrees. They weigh approximately 1300 kilos (2900 lb.) per unit of four and their length is 2 meters ($78\frac{3}{4}$ in.); 25 cm. (10 in.) of this length is used in making contact with the current supply leads.

In the Stassano type of furnace which is operated at Turin and Bonn (France), three-phase current is used. Three or six electrodes are employed (see Fig. 5) corresponding to 500 and 1000 h.p.; these electrodes are round, having a diameter of only 8 cm. (3.15 in.). They form an angle from the horizontal of some 15 degrees. The advantage of circular electrodes is that they can be utilized almost completely because the butts are easily threaded together to form new units, resulting in great economy.

In the production of ferro-alloys electrodes of medium large section are preferable. While they take more time for mounting, they have a lower voltage drop than thick electrodes. If during operation one of the set of four or

* Translated from *Le Genie Civil.*

eight should break, only one has to be replaced, while with thick electrodes a much greater loss in time and material would result. These advantages together with high conductivity have led to the almost universal adoption of sets of electrodes of 4, 8, or 12,

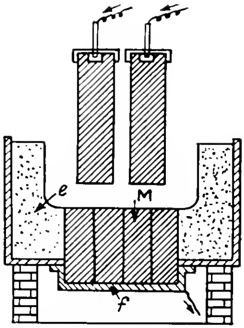


Fig. 6. Furnace with Fixed Hearth Electrodes for Aluminum Manufacture

having 25 centimeter (10 in.) sides approximately, the length varying between 1.75 and 1.90 m. (69 and 75 in.) with a current density of about 4 amps. per sq. cm. (25 amps. per sq. in.) of cross section.

Fixed Hearth Electrodes

In these the electrodes form the bottom or hearth of the furnace and at the same time carry the current (see Fig. 6). The elec-

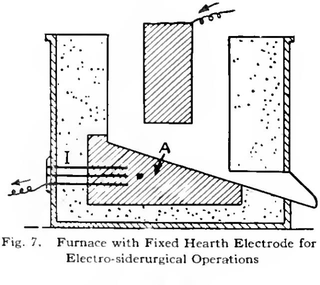


Fig. 7. Furnace with Fixed Hearth Electrode for Electro-siderurgical Operations

trodes are prismatic, M, a certain number being provided in close proximity to each other. They are placed upon a heavy iron plate f, which is in turn connected with an electric cable. The upper part of M forms the hearth level, carbon e being packed tightly around in order to properly close the joints. This arrangement has been adopted in various aluminum smelters.

Occasionally the hearth electrode is formed of a single mass or block of carbon, A (Fig. 7), which is molded in position, the whole container being placed in a baking oven, thus avoiding the liberation of tar vapors at the beginning of the first operation. The current-carrying conductors are generally embedded in the hearth.

In the so-called resistance furnaces, used in the manufacture of carborundum and electrographic coals (see Fig. 8), electrodes E are horizontal and consist of one or more units.

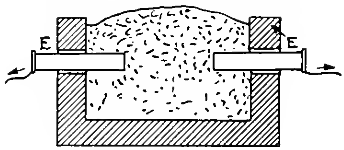
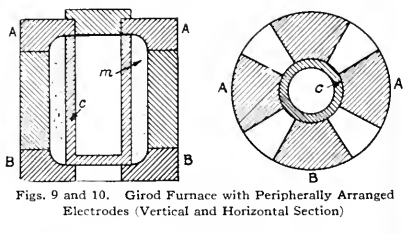


Fig. 8. Resistance Furnace with Horizontal Electrodes

Circular electrodes are employed in certain smelting furnaces and for the preparation of alloys. In the Girod furnace (Figs. 9 and 10), which is of the peripheral resistance type, the electrodes are formed of carbon blocks AA, BB, grouped pairwise in parallel and supplying current to the semi-conducting mass m surrounding crucible C. This form of furnace serves specially for the manufacture of ferro-vanadium by direct combination of the elements.

In the Conley pattern of furnace (see Figs. 11 and 12) the electrodes E, E', are



Figs. 9 and 10. Girod Furnace with Peripherally Arranged Electrodes (Vertical and Horizontal Section)

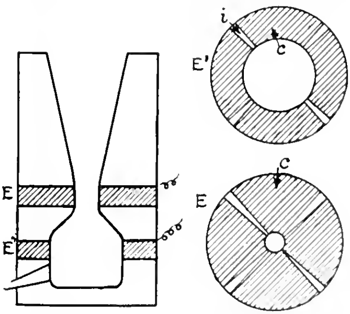
embedded in the brickwork of the furnace and are made up of four parts c which are united by refractory and conducting masses i (graphite).

In a certain model of Heroult furnace employed for the reduction of iron minerals, recourse is had to an electrode hearth *M* made entirely circular and exteriorly protected by refractory masonry (see Fig. 13). This electrode hearth also forms the crucible and goes far enough down to insure the passage of current across the material contained in the furnace. The upper electrode is cylindrical.

Hollow electrodes have also been utilized (Fig. 14). These consist of an assembly of individual parts *A* which are jointed or encased, and serve at the same time for the current supply and the introduction of the materials in the furnace. Electrodes of this type have been used for the production of calcium carbide. Finally may be mentioned the so-called sliding electrodes which are used in certain smelting furnaces where the combustion itself constitutes an electrode which flows off in the course of the process of reaction. In reality there are two fixed electrodes, one being formed by the hearth of the furnace while the other is located at half the height of the furnace; the reducing coal conducting the current to the mineral to be treated.

Calculation of Electrode Length

By increasing the length of the carbons the wastage relative to wear is diminished but the power losses due to Joulean effects are increased. Hence, in each individual case there may be found a definite length for



Figs. 11 and 12. Conley Furnace with Circular Electrodes (Vertical Cut and Cross-section of Electrodes)

which the loss will be a minimum. This is the most economical length. It can be easily calculated by aid of the following formula:

$$\text{Economical length} = l + \sqrt{\frac{2000\, s^2\, ldkb}{arI^2}}$$

where *l* is the mean length of waste when replacing the electrode, *s* the cross-section, *d* the density, *k* the normal mean wear in length per hour (which is well known in practice for every kind of electrode), *b* the difference between the cost price of the

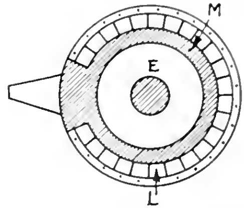


Fig. 13. Circular Fixed Electrode Hearth (M) with Vertical Mobile Electrode (E)

electrodes and the value of electrode wastage per kilo, *a* the cost price per kilowatt-hour consumed, *r* the resistivity of the electrode, and *I* the strength of the current.

Life, Wear, and Protection of Electrodes

The wear of the electrodes in operation, which governs their useful life, is an extremely variable factor because it depends upon a great number of elements, above all the quality of the carbons, the type of the furnace, the mode of protecting the electrodes, and the method of manufacture. The following are the chief causes of electrode wear: (1) Dissociation of electrode on account of the action of the electric current. Unduly high voltages disintegrate a carbon rapidly, whereas an unduly low tension tends to dissolve it; hence, minimum wear and maximum life correspond to a definite potential

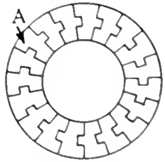


Fig. 14. Hollow Circular Electrode

which could be called the economical voltage. (2) Chemical combination of the electrode carbon with the oxygen of metallic oxides (ores) treated in the furnace. Oxidizing slags cause a considerable consumption of the electrodes by combination with oxides which they enclose. (3) Dissolution of the carbon in the metal isolated in the bath, with formation of carbides, silicid of carbon, etc. (4) Direct oxidation by oxygen in the air. This oxidation is apt to be very rapid in view of the high temperature at which furnaces are operated.

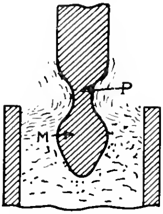


Fig. 15. Electrode Unprotected Against Wear Caused by Oxidizing Gases

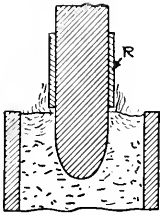


Fig. 16. Electrode Safeguarded from Wear by Means of a Sleeve (R)

Figs. 15 and 16 show two electrodes, the former being unprotected, and the latter protected against wear by means of an insulating non-combustible substance. Part *M* (Fig. 15) which dips or is immersed in the mixture is always protected from oxidation by carbon monoxide set free in the furnace, while portion *P* exposed to the air above the surface of the mixture becomes rapidly oxidized. As a consequence the electrode wears away rapidly at this point and assumes a shape as illustrated. The decrease in diameter increases the resistance, which in turn causes a rise in temperature at the constricted point, and breaking of the electrode results in a short time. By the aid of a protector (Fig. 16) this inconvenience may be obviated.

Electrodes of 1.50 m. (59 in.) length leave sometimes a residual butt of 75 cm. (29.5 in.); hence the waste is 50 per cent. It is true that left-overs are sometimes utilized in the making of new electrodes, for example, by providing them with an inside and outside thread and screwing the butts together. This method is much used in the case of round electrodes made of graphite. Copper screws are also employed for attaching electrode butts (Fig. 17). Sometimes the electrode butts are attached by means of metallic rods *m* (Fig. 18).

The most effective manner of safeguarding electrodes against undue wear, as has been pointed out, consists in lining them with a non-combustible casing or sleeve. For this purpose mixtures of retort coal and silicate of sodium, of lime and lime-stone with additions of carbon, silicate of potash, or of sodium with additions of powdered chalk, have been proposed. These mixtures, spread cold, form a sort of heat-proof varnish coat. Asbestos packing with additions of silicates, white lime milk, etc., are also used. Finally we have recourse to silundum, an amorphous combination resembling carborundum, which can easily be molded and which is at the same time refractory and incombustible. This material is an excellent electrode protector in ferro-silicon furnaces, its component elements being silicium and carbon. Metallic coverings are also used; for instance, a sort of iron grating supporting a paste formed of silicate of sodium and argile, or of kaolin and asbestos. Occasionally, granular substances insensitive to the action of oxidizing gases, i.e., quartz, alumina, carborundum, etc., according to the nature of products to be treated, are embedded in the surface cover of the electrodes. Also rigid covers such as asbestos card board or iron sheets are employed. However, in cases like these it is necessary that the circulation of air and the formation of what may be called a draft jacket should be avoided between the casing and the electrode, as this would promote instead of resist the combustion. For this purpose the following process has been recommended.

The electrode is covered first with a protective layer made of a mixture of magnesium or dolomite which in turn is covered with an envelope of sheet iron about 1 mm.

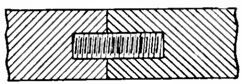


Fig. 17. Central Screw Joint of Two Electrode Butts

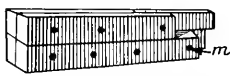


Fig. 18. Contact Joint of Electrode Butts

(0.04 in.) thickness. The first coating is from 3 to 5 cm. (1.2 to 2 in.) thick and is prepared by heating, using as an agglomerating agent from 6 to 7 per cent pitch and from 5 to 8 per cent tar. Adhesion to the electrode can be improved by taking from the electrode surface small pieces of material and filling these places with tar. The sheet laid round the core is held by an outside mold, the agglomerate is then strongly stamped between the sheet and the electrode, the mold taken away, and a joint of plaster, silicate, or refractory earth made in the upper part. This joint is provided to prevent the flame from escaping at the top. It is not necessary to submit the electrode thus protected to a new baking process.

In another method, for which a 90 per cent reduction of wear is claimed, the electrodes are embedded in an agglomerate of coal. For this purpose the electrodes are formed of several cores, from 8 to 10, and the agglomerate consists of a mixture of coke or ground electrode butts, pitch, and tar. The agglomerate acts as a mechanical binder between the core and heat insulator. Since it conducts only a small amount of the current the temperature is lower than that of the cores and the oxidation much less. It also protects the electrodes from air action when the covering sheet has disappeared near the crucible.

Fig. 19 illustrates the position of a protected electrode in a smelting furnace of the crucible type built after Heroult's principle. Protector *P* forms the joint between the furnace and electrode which lengthens the life of the latter by suppressing the flames and action of air upon the surface of the electrode.

It is evident, however, that sleeves or casings are apt to impart impurities to the treated product regardless of the materials from which they are made. Therefore, to manufacture them from any arbitrary mixtures is undesirable. Sometimes it is advisable to dispense with these casings and modify the shape of the electrodes. In several aluminum works electrodes of short length are used of a truncated pyramid form having their large base at the upper end. When no means are provided to safeguard the electrodes from oxidation the employment of short electrodes would minimize the wear despite the lower relative utilization factor.

The specific wear of the carbon electrode compared to a unit of manufactured material varies within wide limits, depending upon the type of furnace and the nature of the products treated. For instance, in the production of ferro-silicon containing 25 per cent *Si*, the wear amounts to about 3 mm (0.118 in.) per hour; when the identical alloy contains 58 per cent *Si*, the wear is 4 mm (0.158 in.). Manganese-silicon combinations cause a mean wear of 3 mm (0.118 in.) approximately, and calcium carbide 2 mm. (0.079 in.). These figures hold good for covered furnaces of the continuous-operation type in which the wear naturally is always greatly reduced.

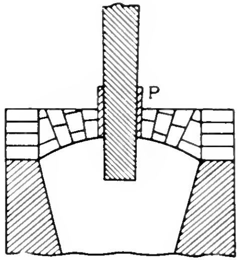


Fig. 19. Protected Electrode

In steel furnaces for direct production using electrodes of 2 m. (79 in.) length the wear varies with the working method. We are giving below, for various mills, the weight of the electrode actually burned away:

	Kilos of Electrode Material per Ton of Steel
Stassano furnace, at Turin	7 10 (15.5–22 lb.) cold charge
Girod furnace, at Ugine	11.4 (25 lb.)
Chaplet furnace, at Allevard. ..	11.3 (25 lb.)
Heroult furnace, at LaPraz ...	17.5 (38.5 lb.)
Lindenburg furnace, at Remscheid	2.68 (4.5 lb.) liquid charge

Taking into account utilizable waste and starting direct from the mineral the mean net wear or electrode consumption lies between 4 and 5 kilos (8.8 and 11 lb.) per ton of steel according to present-day experience. Certain electrodes have shown a useful life up to 1200 hours, which means more than 1½ months' uninterrupted operation.

ELECTRODE HOLDERS—COOLING SYSTEM

The mode in which the electrodes are supported to allow raising and lowering, and the way in which they are connected to the electric mains, are very important factors in the life and maintenance of the electrodes. For instance, improper adjustment may cause the electrode to become overheated, which is conducive to breakage or excessive combustion; and since the resistivity of the carbon diminishes with the increased temperature, which is true also of

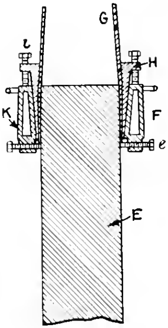
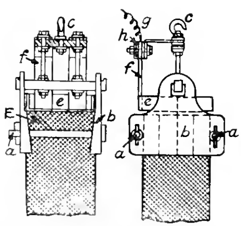


Fig. 20. Clamp Type of Electrode Connection

its chemical resistance, the current follows the path of least resistance and accentuates the trouble.

A faulty method of connection causes excessive expense. Cases are known where the cost of maintaining connections to the electrodes has alone attained a value of 8 Fr. ($1.60) per ton of metal produced, which, for an annual output of 4000 tons, would represent an expenditure of 32,000 Fr. ($6400) per year. Certain improvements



Figs. 21 and 22. Dove-tail Type of Clamping Connection (Vertical Cut and Front View)

have made it possible to gradually reduce this cost to 2 Fr. ($0.40) per ton, or a saving yearly of 24,000 Fr. ($4800).

The electrode holders are connected in various ways, the two chief methods being as follows:

(1) **Clamping Connection**

An example of head support is illustrated in Fig. 20. This comprises a hollow piece *F* whose cavity *K* permits the circulation of water under pressure, providing continuous cooling for the electrode holder. Copper

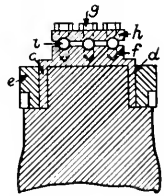
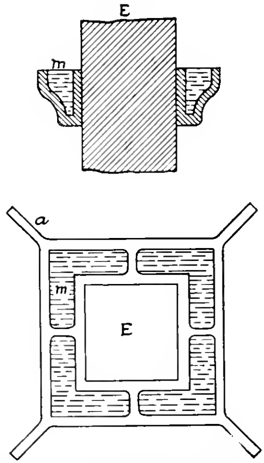


Fig. 23. Clamping and Metallic Joint Connection

pieces *G* suspend the electrode and insure contact between the external electric cables and carbon *E*. They are pressed against the electrode by means of wedges made of cast material or bronze *H* and clamping screw *i*.

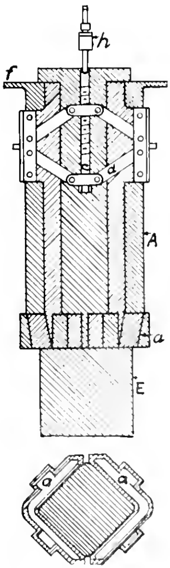


Figs. 24 and 25. Electrode Cooling System (Vertical and Horizontal Cut)

Annular piece *F* carries adjusting screws *e*. Flexible metal tubes are connected with the water inlet and outlet.

Figs. 21 and 22 illustrate an arrangement employed in certain carbide furnaces. The end of electrode *E* cut dove-tail fashion is clamped between cast pieces *b* by the tie bolts *a*. The whole is suspended by an iron support from the hook *c* and is thoroughly insulated. Copper plates *e* and *f* serve to make contact with the current supply cable *g* fixed at *h*. The weight of the electrode tends to make this contact perfect.

Fig. 23 illustrates an electrode of the set-off type over which a copper cap *c* is fitted. To insure good contact the latter is filled with liquid aluminum *d* or some analogous metal with low fusion point. Over the cap is an iron ring fitted on with sliding friction while red hot. By gradual cooling excellent contact is obtained between the copper cap, the aluminum, and the head of the electrode. Cable leads *i* are fixed to pole pieces *f* by the aid of rod *h* and clamping screws *g*. This device gives very good results.



Figs. 26 and 27. Lateral Connection (Outside View and Horizontal Section)

Cooling can be provided in all of these electrodes by a tank placed near the connection or by a circular water sleeve or jacket *m* (see Figs. 24 and 25) surrounding electrode *E*, and if deemed necessary, provided with metallic ribs *a* to increase the cooling surface.

For lateral support an arrangement has been employed in certain furnaces in which steel is made direct from the mineral. Electrode *E* (Figs. 26 and 27) is clamped between two hollow metal pieces *A*, pincer fashion; jaws *a* are V-shaped. The pincers are sus-

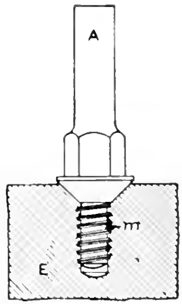


Fig. 28. Connection by Central Cementing

pended from a horizontal beam *h* by means of two rods *c* threaded over a certain portion of their length and connected with the rods called pincers by articulated rods *d*. By turning rod *c* in the desired direction, rods *d* release the rod from the pincers and the jaws exert pressure upon the electrode. When the lower part of the latter is consumed a releasing contrivance attached to the pincer allows the electrode to slide down as desired. By varying the length of the axis of articulation, the same connection device can be utilized for electrode cores of different dimensions, still insuring a good grip on the entire carbon surface. The current supply cables are attached to piece *f*.

The cooling of pieces *A* is effected by circulation of water under pressure. To insure perfect contact between the jaws and the electrode, copper sheets may be interposed when the electrode is out of angle.

(2) Central Cementing

In this method the electrode is fixed to its support by screwing or clamping. In the arrangement illustrated in Fig. 28 rod *A* has a threaded portion *m* engaging electrode *E*. Thus a number of electrodes can be connected to a single supply cable, the whole set, generally four, being supported and controlled from a rack bar operated either mechanically or by hand.

The axial system is preferred in certain cases. An ordinary piece of flat iron *a* (Fig. 29) is often employed in aluminum works as an electrode holder. This can be bent back fish-hook fashion and incorporated in the electrode, either before or after its baking.

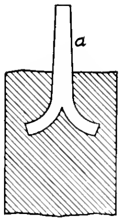


Fig. 29. Axial Connection by a Flat Iron Piece

Fig. 30 illustrates an example of a cemented support (in brass) with a hollow space for water cooling. The water inlet is at *d* in the cup-shaped space of piece *a*; the water flows through *f* forming a part of piece *B*. Any excess water will run over at *g* into annular receptacle *h* where it evaporates without moistening the cementing of electrode *A*.

When the cementing is done as illustrated in Fig. 30, the hollow part of electrode *A* has the shape of a truncated cone; bronze is poured in the space between the electrode and rod *B*. The latter should possess the characteristics of little contraction and low fusion point. The walls of the hole should be heated before the metal is poured. The harmful effect of contraction is obviated by pouring a small tin ring *l* on top of the sealing bronze after cooling. When the electrode is used a quantity of this metal is fused by the action of the current, forming a liquid tin bath which flows into the opening between the electrode and the cementing bronze caused by contraction. A perfect contact is thus insured. The employment of tin is economical, as the metal can be recovered when the electrode is discarded.

In furnaces having small dimensions the electrode support consists simply of a brass mass *M* (see Fig. 31) terminating at its lower end in a threaded rod *e* which is screwed fast to electrode *E*. At its upper end it carries a ring *I* which is connected with the current-carrying conductors.

The control of electrodes is accomplished either mechanically or by hand. Hand regulation is effected by a small motor actuating a winch to which the electrode is suspended, or by the direct operation of the winch. This requires some attention and a corresponding loss of time; therefore, automatic regulation is generally preferred. The Thury type of regulator is extensively used. In this system, which may be operated from alternating or direct current, a controlling device regulates the direction of the rotation of the motor.

The connection of the outside cables with the electrode holders can be effected by screw clamps or by soldering. With this arrangement, however, fusing is possible and some other form of connection is desirable. Some engineers employ copper blades, very thin and flexible, fixed in two symmetric supports and united at different points by rings *b* (see Fig. 32). If the lengths of these blades are slightly different the elasticity of each blade is utilized under the best possible conditions. This arrangement does away with short circuits and the elastic connection is not exposed to the flames of the furnace.

When several electrodes are required for the same furnace, it is necessary that provisions be made for operating the electrodes either separately or simultaneously. This end is accomplished by the aid of revolving supports and electrode regulating boards that allow of several movements.

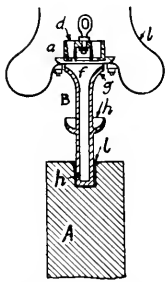


Fig. 30. Central Cementing with Cooling System

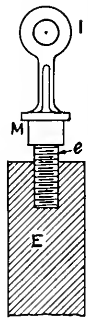


Fig. 31. Simple Screw Cementing

METALLIC ELECTRODES

Tubular Electrodes

A number of furnaces employed in the manufacture of nitric acid are equipped with this form of electrode. In the Schoenherr furnace the electrodes are tubular. One of the electrodes consists of a vertical steel tube whose length varies with the capacity of the apparatus. In the center of this second electrode is an iron core which can be easily replaced when consumed; its life is approximately 2000 hours and about 15 minutes are required to replace it. The arc is established between the tube and copper electrode.

In the Moscicki furnace the electrodes are concentric. The outer is a copper cylinder of 15 cm. (6 in.) diameter mounted in a clay base. The central electrode is a tube of 6 cm. (2.36 in.) diameter arranged for cooling by water circulation. Its upper part, through which the current enters, is fixed in a porcelain mounting. The arc is established between these two cylinders which are rotated magnetically.

In the Birkeland-Eyde furnace the two electrodes consist of simple copper tubes bent U-shaped and cooled by a current of water. They are subject to but little wear and are easily accessible and replaceable.

Horn Electrodes

Metallic electrodes of the horn type are utilized in the Guye and Pauling furnaces. In the latter (see Fig. 33) the electrodes, *EE'*, are arranged in a manner similar to a horn type lightning arrester. The electrodes are made of cast steel, hollow to permit the circulation of water, *ab*, and are interchangeable and reversible. The arc is established at *A*, the narrowest point; blown by an air stream directed from *m* towards *n*, it climbs up very rapidly between the two legs of the V formed by electrodes *E* and *E'*. The nitrogen gases generated in the furnace escape through *n*.

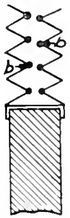


Fig. 32. Flexible Electrode Support

Massive or Solid Electrodes

Massive metallic electrodes are utilized in certain furnaces for the production or smelting of metals. Preferably electrodes made of the same material as the metal to be molten are employed. For instance, in furnaces intended for the fusion of steel or iron, iron electrodes are used, while in furnaces for the smelting of copper, bronze, or brass, copper electrodes are resorted to. However,

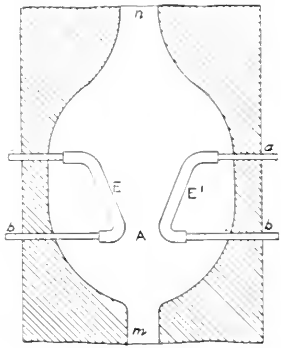


Fig. 33. Hollow Cast-steel Electrodes for Furnaces to Produce Synthetic Nitric Acid

in some furnaces of simple construction employed for fusing, an iron or copper anode of large dimensions embedded in rammed graphite carbon is used (Fig. 34).

In the canal and sump type of steel furnace each electrode (Fig. 35) consists of a block of soft steel *A* at the ends of canal *b*, surrounded by the metal to be treated. The steel block has an interior annular cavity *m*

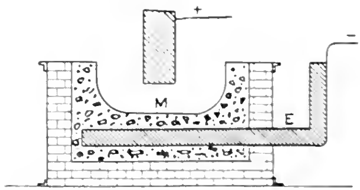


Fig. 34. Furnace with Metallic Electrodes Immersed or Embedded in Rammed Carbon M

through which cold water is circulated. This prevents fusion of the electrode by the liquid metal in contact with point *a*. The electrode is enclosed in refractory mass *R*, which constitutes the furnace proper.

In the Girod furnace (Fig. 36) the metallic pole *M*, made of steel, is placed laterally in the refractory masonry of the furnace. The lower part of crucible *A* is previously filled with pieces of the same metal that is being made in the furnace. After solidification, this part protects pole *M*, which in addition is cooled by circulating water; hence the reduction and smelting process really occurs inside zone *B*.

Hearth Electrodes

Metallic hearth electrodes, i.e., metallic poles embedded in some refractory non-conducting material, are of various forms. One of the first furnaces of this type was

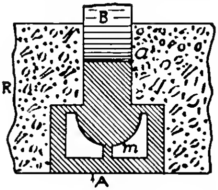


Fig. 35. Steel Electrode for Resistance Furnace Gin System

designed by Siemens in 1880. Vertical electrode *M* (Fig. 37) is made of carbon, while the bottom electrode *E* is made of iron rod. By means of a screw mechanism this can be fed into the furnace as it becomes worn. In the Borchers forms of furnace (1896), the lining of bottom *M* (Fig. 38) is made of steel. In a mass of the same metal is fixed a copper piece *R* cooled by circulating water, the water flowing out of pipe *E* in the direction indicated by arrows.

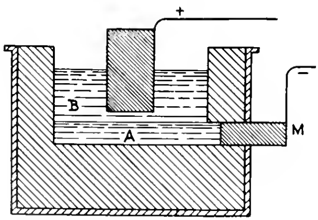


Fig. 36. Steel Electrode for Electro-siderurgical Furnace System Girod

In the more recent designs of Girod furnaces the poles are made either of graphite coated with metal, or wholly of metal. In the former design (Fig. 39) the metal coat enclosing the graphite serves to protect the metal contained in the furnace from the carburating contact of the graphite. Poles *P* are embedded in the masonry of the furnace. The current flows from each of these blocks to upper electrode *E* over separate paths, as indicated in the illustration by broken lines. By this means it is made to traverse the

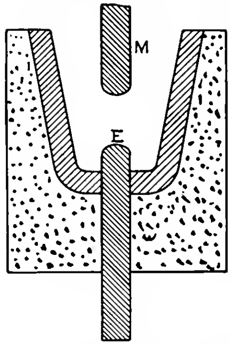


Fig. 37. Furnace with Metallic Hearth Electrode

whole layer of metal contained in the apparatus.

In the second design (Fig. 40) of the Girod furnace a multiple of steel poles *P* are provided; these are cooled at their lower end and terminate in channels *c* formed in the

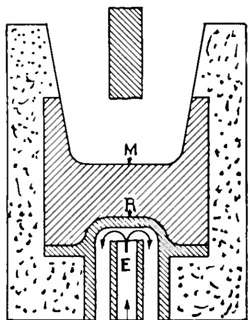


Fig. 38. Furnace with Metallic Hearth Electrode and Water Circulation

brickwork structure. As in the furnace illustrated in Fig. 36, these channels are previously filled with metal to safeguard poles *P* from fusion. The poles are arranged in parallel at the entrance of the furnace. The masonry *M* is built in a manner to prevent excessive heat conduction as a result of the high temperatures obtained during operation.

MIXED OR COMPOSITE ELECTRODES

Conducting Ramwork

Making the hearth of pure carbon sometimes involves serious complications, notably in the electro-metallurgy of steel, for the reason that carbon exercises a carbonizing action upon the mixture, with the result that it is impossible to obtain products with low carbon content. This condition can be remedied by making the hearth of magnesia. and adding carbon to promote conductivity. The hearth electrode so constituted does not become a metallic conductor; it is formed of ramwork consisting of a mixture of a carbonated substance (pitch, graphite, tar) and a refractory substance (magnesia, dolomite, silica). The percentage of these ingredients may vary with the layers or thickness of the hearth; for instance, the uppermost stratum on which the steel rests could be made rather poor in carbonaceous substances in order that the carbon content of the steel may not be affected.

In the Firminy steel works, where furnaces built on this principle are installed, many different compositions have been tried and good results obtained. Tar is employed as

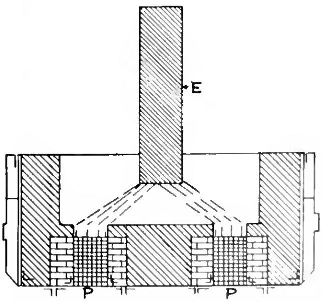


Fig. 39. Girod Furnace with Metallic Poles Embedded in Refractory Masonry

the binding agent. If less than 2.5 per cent tar is used the mixture fails to bind, while if more than 10 per cent it becomes unduly liquid. The chief mixtures that have been utilized are alternatively cast-tar-dolomite (calcined) and graphite-tar-dolomite (calcined). With these mixtures it is easy to obtain refractory hearths containing from 10 to 20 per cent C, which become good conductors at high temperature after the first heating. The first casting naturally contains slightly more carbon than normal,

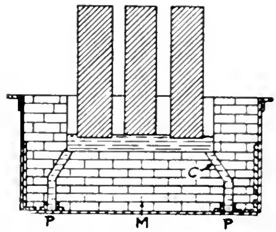


Fig. 40. Girod Furnace with Channel-forming Metallic Poles (P)

as this condition is due to the liberation of tar in the first process. The following are some typical figures covering the melting of steel chips containing 0.16 per cent C, 0.360 Mn and 0.349 per cent Si:

	First Cast Per Cent	Second Cast Per Cent	Third Cast Per Cent
Carbon	0.226	0.102	0.140
Manganese	0.161	traces	0.073
Silicium	0.060	0.027	0.069

The second and third casts are normal; hence the carbon enclosed in the hearth does not interfere to an appreciable extent. Another fact worth mentioning is that but little repair work is required in the hearth.

Casting Electrodes

Some designers have utilized a vertical electrode consisting of a mixture having as a constituent the metal or a combination of the metal that is to be added to the molten charge. For example, in the production of ferro-tungsten a furnace is employed which is equipped with two vertical electrodes composed of carbon and cast tungsten arranged in series. The bath contained in the crucible consists of a mixture of iron oxide and dioxide of tungsten. The electrodes of carburated tungsten pass into fusion as soon as the furnace is in running order; the carbon is burned and eventually an alloy containing only from 0.15 to 0.25 per cent C is obtained

Mixed electrodes can likewise be utilized for the production of ferro-molybdenum. Their inventor has given them the name of casting electrodes.

Reinforced Electrodes

Other attempts have been made to increase the conductivity and mechanical strength of carbon electrodes by giving them an axial core. For instance, Heroult hollowed his electrodes and filled the space with a mixture of aluminum and silicon. The Plania-Werke, of Regensburg, equipped their electrodes with copper or iron bands either before or after baking. This plan is particularly applicable to very long electrodes, as it increases their mechanical strength and solidity. Attention may be further called to the electrodes made of carbon or iron tubes filled with lime, iron oxide, or other slag-forming substances, which, in the course of the process, liberates the refining slags at the hottest point of the metallic bath.

Reinforced Coffer Construction

Finally may be mentioned a conducting coffer construction devised by Keller, as follows:

Iron bars *A* (see Fig. 41) having sides varying between 25 and 30 mm. (1.00 and 1.18 in.) are placed vertically and made integral with a metallic plate *P* to form the bottom of the apparatus upon which the liquid steel *a* rests. The coffer construction consists of a second-class conductor (e.g., magnesium) rammed between groups of four bars, which practically constitutes a mold allowing considerable compression of the mixture between the bars *A*.

Hearth electrodes thus constructed facilitate starting the furnace, because the iron bars which are arranged close together and flush with the top act as conductors. These bars are placed in parallel and the distribution current is very uniform. The resistance of the whole hearth, electrode is practically negligible. The liquid metal rests directly upon the hearth the mechanical strength of which is very high. Cooling is secured by means of water circulation, *i*.

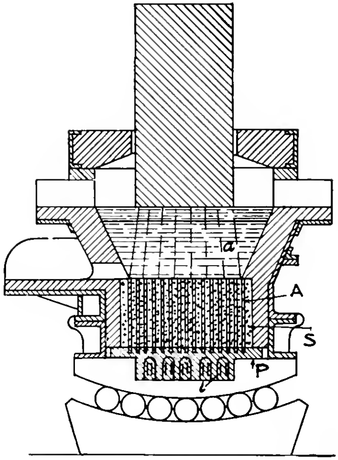


Fig. 41. Furnace with Armored Conducting Material, Keller System

The life of these hearths is very long, as the substance uniting the bars *A* hardens in the course of time, and results in a non-carburating hearth as perfect as is feasible in practice. Its functions in metallurgical operations are simple and reliable and its industrial losses are very small.

Nitrogen Fixation Furnaces

By E. Kilburn Scott

Some of the salient points of difference between electric furnaces for the fixation of nitrogen and those for metallurgical purposes are referred to in the opening paragraphs of the following article, which is an abstract of a paper read by the author at Thirty-fourth General Meeting of the American Electrochemical Society, Atlantic City, Sept. 30–Oct. 2, 1918. The furnaces for fixing atmospheric nitrogen are classified into three groups in accordance with the means employed to direct the arcs, and typical furnaces of each type are described. The remainder of the article is devoted to a discussion of various features in the operation of nitrogen-fixation furnaces; such as, phase balance, starting, losses, electrodes, stabilizing the arc, power-factor, air supply, preheater, absorption, cooling the gas, and theory of the reaction.—Editor.

Arc furnaces for fixing atmospheric nitrogen differ from arc furnaces for making alloys, carbide, etc., in that instead of the electrodes being of carbon they are made of special metal, which wears away very slowly. Also, the potential used is several thousand volts which necessitates better insulation. Another difference is that air only is used or charged; the internal construction is therefore simpler as regards the refractory lining, for there is no melted metal or flux to react with or to cut the brickwork.

The furnaces are especially suited for intermittent working with off-peak power, because they can be started and stopped at any moment with almost the same facility as an ordinary arc lamp, and there is no fused material to be run off or to freeze in case the supply of electricity fails; also, after starting up again, full yields are obtained very quickly. The furnaces may therefore be advantageously installed wherever cheap three-phase power is available for say 16 or 20 hours a day, and this is the only type of furnace for fixing atmospheric nitrogen that can be so used.

A convenient size of air nitrate factory is one to take about 10,000 kw., but of course the larger the factory the lower the cost per kilowatt of plant installed, and the lower the working cost and of overhead charges per unit of finished product.

The ordinary standard voltages of 5500 and 6600, and periodicities of 25 and 60 per second are suitable, so it is not necessary to install special generating machinery. The energy can be tapped from a general transmission network, although there are advantages in having the factory near to the power house.

To combine nitrogen and oxygen efficiently by electricity, it is necessary to obtain as intimate contact as possible between the gases and the arcs.

Types of Furnaces

For the purpose of discussing the types of furnaces, they can be classified as follows:

(a) Designs having mechanically movable parts.

(b) Designs employing a magnetic field to direct the arcs.

(c) Designs depending only on air currents to direct the arcs.

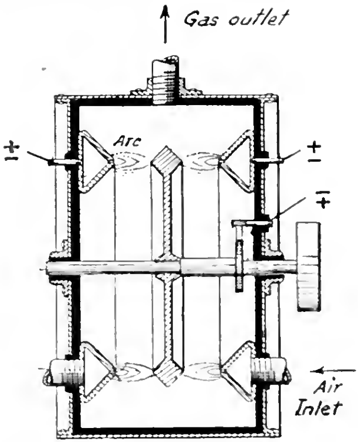


Fig. 1 The Island Furnace with Mechanically Rotated Arc

(a) Designs Having Mechanically Movable Parts

The Bradley and Lovejoy apparatus as it was installed at Niagara Falls is historical, and it is interesting because it is a distinctive type. It depended on the formation, prolongation, and interruption of many thousands of sparks or arcs per second, each one separate from the rest. The arcs were produced by rotating an iron cylinder fitted with platinum points inside a fixed enclosing cylinder having an equal number of points. Direct current at 10,000 volts was employed, partly because the apparatus was built at a time when that form of current was generally in use. It was afterwards appreciated that it would have been better to work with alternating current.

MacDougall and Howles, who were working on the problem in England about the same time, employed alternating current.

Another design depending on mechanical movement is that of J. Simpson Island of Toronto.

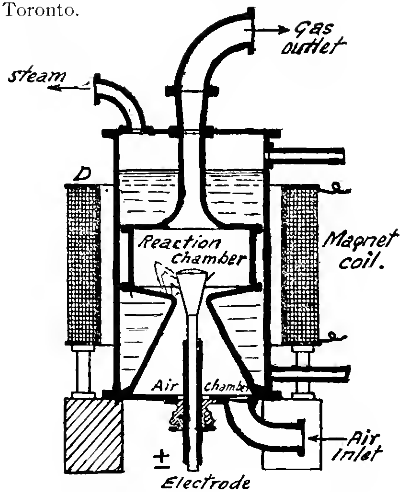


Fig. 2. Moscicki Single-phase Furnace Having Magnet Coil to Give Rotation of Arc

As will be seen from Fig. 1, there are in this furnace four V-shaped rings, two of which rotate, and the electric arc which would normally remain stationary at the shortest gap is drawn around. To the eye it looks like a ring of flame, but in reality it is a single arc rotating rapidly round the annulus. Air passes through perforations in the apices of the stationary rings.

The Rankin furnace, to which T. H. Norton draws attention in an article in *Scientific American*, Sept., 1917, has been tried in California. It is a distinctive type because the arcs are mechanically caused to move through the air, instead of the air being blown through the arcs. The sparking points are fitted in a sort of piston which reciprocates in a cylinder and at the same time is rotated to and fro by a thread on the spindle. Current is led to the sparking points by wires through the hollow spindle.

(b) Designs Employing a Magnetic Field

The Moscicki furnace, used in Switzerland, has a magnetic field which causes the arc to rotate round an annular opening. Referring to Fig. 2, there is a reaction chamber with an air chamber below, both of which are surrounded by water. The annular opening is formed between a high-tension electrode and the lower edge of the reaction chamber, which latter is earthed. Magnet coil *D*, acting in conjunction with the steel construction of the furnace, sets up a magnetic field across the annual opening which causes the arc to rotate.

The Birkeland-Eyde furnace used in Norway, France, and Spain has also a magnetic field, but in this case it forces the arc into two half disks of flame, which alternately rise and break in the top half and in the bottom half of the reaction chamber. The electrodes, see Fig. 3, are of copper tubes supported on ball insulators, and they project into a circular reaction chamber, the side walls of which are pierced by a large number of small holes. Air passing through these holes strikes into the flame at right angles.

(c) Designs Depending on Air Currents

In the Schoenherr furnace, as used in Norway, air is blown tangentially into the bottom of a vertical reaction tube made of steel, and in passing upward with a whirling motion it maintains a rod-like arc in the center. To distinguish this arc from those of other furnaces, the writer calls it a "standing arc." The cross section of the reaction tube, see Fig. 4, is about 30 sq. in. (190 sq. cm.), whereas the section of the arc is only a small fraction of a square inch.

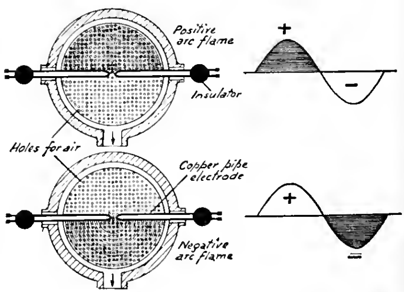


Fig. 3. Alternating Arc Flame of Birkeland-Eyde Furnace

A point of interest is that this design is the only one which has an air preheater combined with it. This takes the form of annular tubes, as shown in section in Fig. 4, through which the hot gases and the air pass in contra-flow directions.

The Wielgolaski furnace, used by the American Nitrogen Products Company of Seattle, Washington, also has a standing arc, but instead of being similar to a single straight rod it is in the form of a "bight" having its ends springing from electrodes at the bottom. For a given voltage, the height of the arc is therefore considerably less than

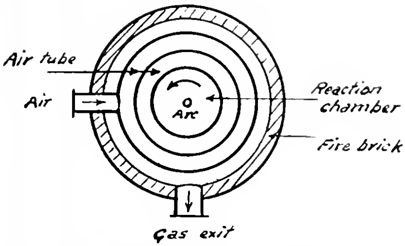


Fig. 4. Cross Section of Reaction Chamber and Annular Prebeater Tubes of Schoenherr Furnace

in a Schoenherr furnace. The electrodes are hollow and air is blown straight through them without any whirling motion.

The Pauling furnace, used in Italy, Austria, and Germany has a fan-shaped arc flame which forms between horn-shaped castings. Below the electrodes there is an air pipe having a narrow slot, the idea being to get as much air as possible into the flame, but as a matter of fact it spreads out in all directions as indicated in Fig. 5. Fig. 6 shows a

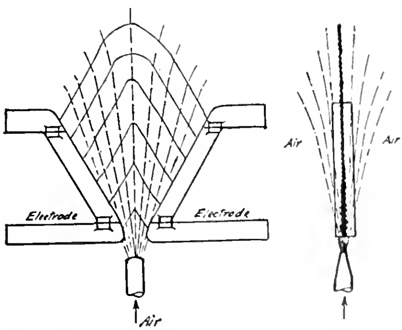


Fig. 5. Arc Flow in Relation to the Furnace of a Pauling Arc

modification installed at Nitrolee, S. C., and due to R. Phaehler and I. Heckenbleckner. Each electrode is supported at the bottom only, and the cooling water enters and leaves at that point, experience having shown that an upper connection causes short circuits and is difficult to insulate. Air is blown through two nozzles, the inner one passing a relatively small quantity at high pressure so as to cool the kindling blades. The bulk of the air which is preheated passes through the outer nozzle at low pressure. The power is therefore less than would be the case if all the air were at high pressure. Each side wall between the electrodes and just above the zone of maximum heating has a duct through which are blown the gases from the furnace, which have been cooled down. The object is to cool the highly heated nitric oxide below the critical temperature of dissociation,

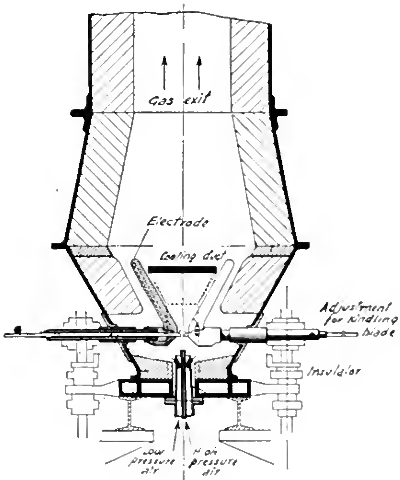


Fig. 6. Modification of Pauling Design Due to Pfaehler and Heckenbleckner

and as the return gases contain practically the same percentage of nitric oxide gas as the freshly treated gas, there is no dilution.

Furnaces which work with single-phase alternating current have to be used in sets of three on a three-phase supply, whereas the Kilburn Scott type uses all three phases in a single reaction chamber.

The Kilburn Scott furnace, shown diagrammatically in Fig. 7, has three wedge-shaped electrodes arranged with intervening refractory material so as to enclose a six-sided conical space, having its apex at the bottom. Three-phase current supplied to the electrodes produces a combined arc which is flared out by the air, and with 60 periods gives 360 flames per second.

By drawing three sine curves with a phase displacement of 120 degrees, as in Fig. 8, it is seen that current is always flowing in the reaction chamber, and it can be shown

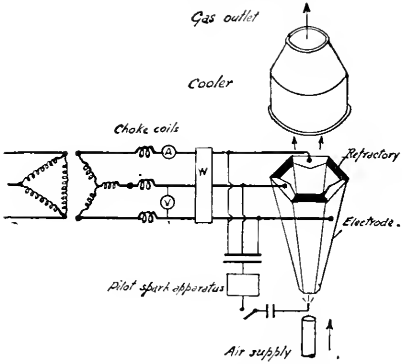


Fig. 7. Diagram of Kilburn Scott Three-phase Furnace

mathematically that the power-factor varies between 0.86 and 1.0. On the other hand, with the single-phase furnace, the power-factor varies from zero to maximum, and twice in each cycle there is no current.

The flame appears to the eye like a double cone having one apex at the bottom, where the electrodes are nearest together, and the other at the top, where the flame tapers off. The flames flicker about with great rapidity in different planes, and so are constantly intercepting fresh particles of air. Fig. 9 indicates how it revolves, the speed of revolution corresponding to the frequency.

Balance of Phases

From the point of view of the supply of electric energy, it is desirable to have all three phases balanced, and this is especially necessary when current is purchased from a public supply company, for the general supply must not be affected by low power-factor and unbalanced and variable loads.

When single-phase furnaces are connected to a three-phase supply, there may be considerable lack of balance when one furnace drops out of circuit; also, at starting up, unless all the furnaces are switched in together. If one arc fails, there is a possibility that the circuit breakers of the other furnaces may trip, with the result that a heavy load is suddenly thrown off, and a surge may set up.

The three-phase furnace gives no trouble in this way, for it functions as a single unit and the phases balance automatically. Even if deliberately set so that they do not balance, they tend to equalize by burning at those points where the current is greatest. There is very little chance of a three-phase furnace failing altogether, because the three phases help to maintain one another.

Starting Up the Furnace

As the electrodes of nitrogen fixation furnaces are of metal and work at high voltage, they must not be brought into contact. Starting is usually effected by carefully moving the electrodes until they are near enough for current to jump across. After running until the interior has become heated, the electrodes are withdrawn to the regular working distance. Adjustment must be made carefully to minimize the rush of current, and as this depends on the furnace attendant, the amount of reactance in circuit has to be sufficient to allow for the contingency of careless operation.

The Schoenherr furnace is started by means of a lever which is moved by hand until it is near enough to the lower electrode for the current to jump across. The lever is then withdrawn and the whirling air carries the arc to the top of the reaction tube. In case the arc fails it has to be rekindled by hand, so considerable attention is necessary.

Pauling uses the device shown in Fig. 10, which shows two furnaces connected in series in each leg of the three-phase supply, and an auxiliary transformer connected across one pair of electrodes in each series.

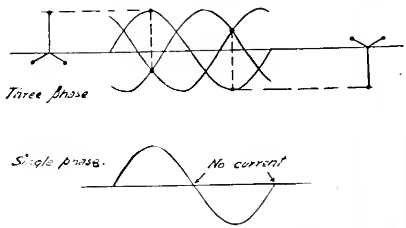


Fig. 8. Comparative Curves of Three Phase and Single Phase

The high-tension coil of this transformer gives a voltage several times greater than the main supply, so that if an arc fails the current which is shunted through the primary immediately induces a higher voltage to again start the arc.

While experimenting with an early model of the Kilburn Scott three-phase furnace, it was found possible to use pilot or trigger sparks to break down the air dielectric and thus dispense with movement of the electrodes for starting. This is a simple solution of the problem, and does away with the uncertainty of operation by an attendant. A wire, placed midway between the three electrodes just above the central air nozzle, is connected to an extra high tension supply which causes sparks to jump from the wire to the electrodes, thus ionizing the air and causing the main current to flow. The more pilot sparks there are in a given time the better the effect; also, the higher the frequency the less the air resistance.

Size of Furnace

Speaking generally, the larger a furnace the more accessible are the interior parts and the easier it is to adjust and renew the electrodes. Radiation losses are also relatively smaller, and the percentage of energy absorbed by the reactance coils being less, the power-factor tends to be higher.

Radiation and Cooling Water Losses

In the Schoenherr furnace, radiation accounts for 17 per cent of the loss and the

Doubling the number of electrodes means doubling the pipe connections and fittings, also electric cables, etc.; and as the water connections must necessarily be connected to the high-tension supply, it is an advantage on this account to have as few as possible.

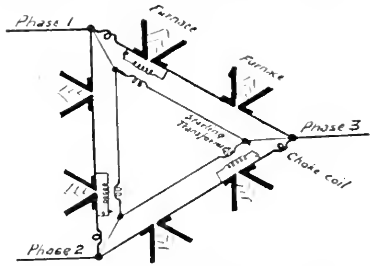


Fig. 10. Pauling Furnaces in Series on Each Phase and Starting Transformers

In furnaces with diverging electrodes, heat is principally generated about one third the way from the bottom, so the cold water should impinge at about that point in order to keep the metal from being worn too rapidly. At the same time, in order not to reduce the temperature of the reaction chamber too

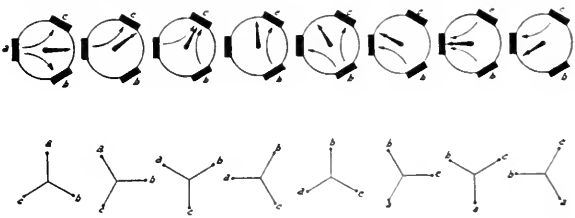


Fig. 9. Diagram Showing Rotation of Three-phase Arc

electrode cooling water for about 30 per cent. It is therefore desirable to design electric furnaces with as small radiation surface as possible and with a minimum of electrodes through which heat can pass to the outside air.

Radiation loss varies directly as the wall area of the furnace, and cooling water loss may be said to vary with the number and the size of the electrodes. Two electrodes being the least that can be used for any one furnace, it follows that three single-phase furnaces must have six electrodes while a three-phase furnace of the same total power has only three.

much, it is necessary to adjust the amount of cooling water carefully.

Electrodes

The writer's conception of a blown arc flame is that it consists of arc threads or streamers which strike across the bottom of the electrodes, and then acting like flexible conductors are carried up by the air current. The ends move rapidly over the surface of the electrodes until the arcs have reached the maximum length at which the voltage will sustain them, when they snap suddenly and new arcs are started.

If the formations and extinctions of the arc threads synchronize exactly with the alternations of the electric current, then the furnace is working smoothly and it is easy for those accustomed to such furnaces to know this by the sound.

Round each arc thread there is a flame of burning nitrogen, and as nitric oxide forms it diffuses away into the surrounding air and in so doing becomes cooled. Probably the quickest chilling takes place at the moment when each arc thread breaks.

The arc also tears particles of metal from the electrodes, and these becoming incandescent and oxidized may play some part in expediting or retarding the reaction, for it is known that some metals are better than others, from the point of view of yield of nitric oxide.

With diverging electrodes, the ends of the arcs travel along the surfaces in leaps, which is possibly due to softening of the metal, and the arc is momentarily held at each point until the force of the air (or magnetism in the Birkeland-Eyde furnace) overcomes the adhesive tendency.

When the surfaces of the electrodes are large, the wear is relatively slow and the electrodes only need renewal at long intervals. On the other hand, when the arcs spring from the end of an electrode, as in a Schoenherr furnace, burning is intensive and the electrode has to be fed forward regularly.

The electrodes must be of a metal which has a high melting point and is not readily oxidized, also it should be a good heat conductor so as to pass heat quickly to the cooling water.

Steel is used in the Schoenherr and Moscicki furnaces, but the magnetic oxide of iron to which it burns may be carried over to the absorption towers and stain the acid. Steel begins to oxidize at about 370 deg. C., and oxidizes rapidly at about 500 deg. C.

Nickel has an ignition temperature of about 650 deg. C., but it is too expensive to use, and this remark also applies to many metals and materials which have high melting points, platinum for instance. Those working on the nitrogen fixation problem are always on the lookout for better electrodes.

In this connection, the process called "calorizing" is of interest, because it increases the heat resistance of metals. The process depends upon the fact that at high temperature and in a neutral atmosphere powdered aluminum will enter into combination with a metal and form a homogeneous alloy which cannot be destroyed except as part of the mass of which it is part. The depth of the impregnation depends on the length of time of the treatment, and by it the oxidizing temperature of steel can be raised to over 1,000 deg. C.

Copper is a good metal to use for electrodes, because it is easily made to the required shape and wears away smoothly without releasing troublesome vapors. After a run with some copper electrodes which were fastened by steel screws, having their countersunk heads in line with the path of the flame, it was noted that the steel was considerably burnt, whereas the surrounding copper had only slight surface marks.

It is important to minimize the oxidation, because when a considerable amount of electric energy is employed in vaporizing metal there is so much less energy for exciting the gas molecules and bringing about the nitric oxide reaction.

Birkeland-Eyde furnaces use tubes of pure electrolytic copper about 2 inches (5 cm.) in diameter and $\frac{3}{16}$ inch (5 mm.) thick, bent into the form of a U, each leg of which is about 8 feet (2.4 m.) long.

Electrodes of copper alloyed with other metals have been used to advantage, and those metals which show good nitrogen bands in the arc spectrum are obviously the better ones to employ.

There is some reason to suppose that the presence of metals or oxides of metals act in a catalytic way in increasing the velocity of the reaction. The action of a catalyst is supposed to be such as to make it unnecessary to use higher temperature to get a workable velocity.

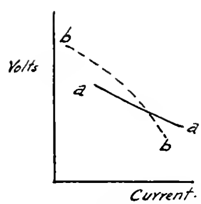


Fig. 11. Characteristics of Arc and Alternator

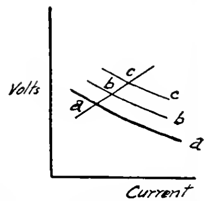


Fig. 12. Falling and Rising Characteristics of Electric Arcs

Stabilizing the Arc

For smooth electrical operation it is important to have the arc stabilized, and this is the condition which gives good yields of nitric oxide. Furthermore, it is important to have the furnace working easily, because of the effect of an unstabilized arc on the supply circuit.

An ordinary arc lamp works well because the carbons are automatically moved so that the distance between them increases with current, to effect which an electro-mechanical device is used. This is possible because the parts to be moved are small and of light weight, but obviously the heavy metal electrodes of large electric furnaces, and the large power involved, present a much more difficult problem.

The resistance of an alternating arc varies with current in such a way that when the voltage between the electrodes decreases the current then increases. In other words, the characteristic of the arc is a falling one, as shown by curve *aa* of Fig. 11. If the voltage of supply can be made to fall in accordance with the arc characteristic, then complete stability of the arc is obtained, but the only course is to specially design the alternator for a large voltage drop, as shown by curve *bb*. The writer has used such an alternator with good effect; and it is of interest to note that the latest installation in Norway, at Rjukan II, has alternators with large voltage drop, each supplying a group of three single-phase furnaces of 4,000 kw.

When an air nitrate factory receives energy from a transmission line so that step-down transformers are required to reduce the voltage to that required by the furnaces, then reactance may be embodied in the transformer. The transmission line itself and the various connections may also give some reactance which goes toward reducing that necessary in the separate reactor.

It is obviously desirable to design a furnace so as to work with as little reactance as possible, and one way is so to design the electrodes that they require little or no adjustment, for obviously reactance must be larger if the contingency of inexpert adjustment has to be met.

Stabilizing an arc against what may be called abnormal conditions may be done by automatically varying the force of the air in accordance with the current in the arc, for increased air pressure increases the arc voltage. With varying air pressures the arc characteristic will move out parallel to itself, as shown in curves *bb* and *cc* of Fig. 12. An automatic device may be employed to do this, so giving the equivalent of a rising characteristic, as shown by curves *a*, *b*, and *c*, Fig. 12.

F. G. Liljenroth has patented such a device; and for a Birkeland-Eyde furnace (see Fig. 13) he provides a regulating switch in the field-magnet circuit, which switch is varied by a solenoid through which the current of the electrodes passes.

Power-Factor

The expanding arcs of electric furnaces give a capacity or leading-current effect,

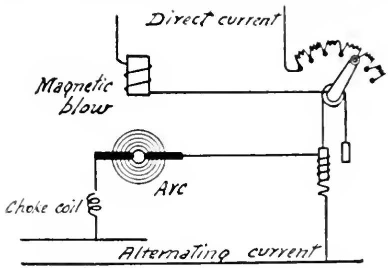


Fig. 13. Device for Stabilizing the Arcs of Birkeland-Eyde Furnace

and but for the large amount of reactance used to steady the furnace the power-factor would be high. With diverging electrodes the arc at the commencement of each half period is small and gradually lengthens until it breaks, so the resistance may be represented by the rising line of Fig. 14.

The low resistance causes the current at the beginning to be large as indicated by the exaggerated current wave of Fig. 14. When compared with the voltage wave the effect is as if the current were leading, and in practice such is found to be the case.

Diverging electrodes also act with the air between as a sort of condenser, and a feeble spark is sometimes noticed between the tips of the electrodes where they approach nearest together, due to the condenser action.

In the Birkeland-Eyde furnace, the interaction of the magnetic field with the alternating current passing between the electrodes is also said to cause the current to lead. The power-factor is certainly higher than with the Schoenherr furnace; and this may be due to the latter having a steel tube around the long arc, which gives an inductive effect such as would be the case if armor were placed around a single conductor carrying alternating current. Dr C. P. Steinmetz considers that the "standing arc" of the Schoenherr furnace acts in the opposite way to the expanding arcs of other furnaces, and the resistance of the arc being high at the start causes a current wave distortion which is equivalent to a lagging current.

Reactances

Small choke coils or reactances can be made with adjustable iron cores; also the regulation of series arc lighting can be effected by an apparatus having movable coils. It would be useful to have such readily adjustable reactances for electric furnace operation, but as the power required for furnaces is very considerable it is difficult to keep a movable core or movable coils steady enough, and probably also the core would become too hot.

It is not possible to alter the amount of reactance by altering the number of turns of a choke coil, because the one connected to the switch contacts would act for the time being as a short-circuited secondary, and very large currents would be induced that could not be safely switched off.

One way to alter reactance while the furnace is running is to change the connections of the coils from series to parallel; another is to have a number of reactances in parallel and change the number of them in circuit. This latter method is employed for the 4000-kw. Birkeland-Eyde furnaces. When starting such a furnace that has been relined the method is to switch in only one of three reactors, and to allow only about 1400 kw. to pass. As the lining dries out, the other reactors are switched in one after the other until the furnace receives the full 4000 kw.

During early experiments with a Kilburn Scott, three-phase furnace, it was considered desirable to interpose transformers of one-to-one ratio between the furnace and the alternating-current supply, so that in case any abnormal condition occurred, a magnetic link between the two circuits would act as a protection to the alternator. By suitably adjusting the sectional area of the core and the disposition of the coils, the magnetic leakage varied with the current and the regulation was very good.

Although many reactors are built with iron cores, there is a tendency to dispense with the iron because reactors without it are more accessible, and as the conductors are of bare copper supported in cement concrete they are fireproof.

A neat form of reactor made by the General Electric Company is shown in Fig. 15. The conductor is bare copper wire, wound in slightly conical layers, the turns of the first layer progressing from outside to inside and of the second layer from the inside to outside, and so on. The layers converge where the voltage is a minimum, the clearance between turns being about an inch (2.5 cm.) for 6600 volts. The concrete is freed from metallic particles and is cured in the presence of high-pressure steam, and the whole is supported from the ground by porcelain post insulators.

Air Supply

The yield of a furnace depends to some extent on the condition of the air blown through the arc, for if charged with dust particles, moisture, or oil, or the acid vapors of large industrial centers, results are not so good as when the air is clean and dry. While working an experimental plant in Manchester, England, it was found that the yields on moist days were lower than when the atmosphere was comparatively dry.

The air should have an easy flow from the blower to the furnace, that is to say,

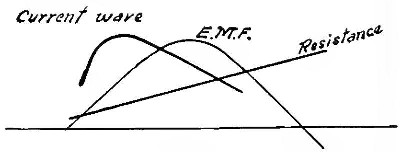


Fig. 14. Showing the Effect of Arcs which Increase in Resistance

the pipes should be short and straight as possible and the branches of similar length, so that each furnace receives the same pressure.

Expanding nozzles have been recommended for delivering air to the flame, but the writer has found them liable to set up throbbings in the air flow. To get even flow, the pressure at the discharge has to be about half the initial pressure, and this condition is not easy to meet with air at low pressure and high velocity because the expanding portion must be excessively long.

Air compressors of the reciprocating type are not suitable for the supply of air to nitrogen fixation furnaces, because the air must flow in an absolutely steady stream and be free from oil, etc., also such compressors are only efficient for pressures above 15 lb. per sq. in. (1 atmosphere).

Pressure blowers such as the Root type may be used, but as they also work by pocketing air and carrying it over to the delivery side, the pressure is somewhat uneven. They work efficiently with pressures up to about 8 lb. per sq. in. (0.5 atmosphere).

Fans give a steady flow, but are inefficient because they do not use the velocity energy of the air at the impeller exit. Also they are only good for pressures below 1 lb. per sq. in. (0.07 atmosphere).

Centrifugal compressors are best because they are efficient and deliver a steady stream of air at pressures necessary for the furnaces. They resemble a centrifugal pump in having a rapidly rotating impeller surrounded by a stationary set of discharge vanes supported by the casing. For pressures up to 4 lb. per sq. in. (0.25 atmosphere) one impeller is used, and higher pressures are obtained by merely multiplying the number of impellers. The speeds are suitable for coupling them direct to either steam turbines or 60-cycle induction motors. With 25 cycles, the motor speeds are lower and gearing has to be used.

Preheater

Preheating the air before it enters the furnace is advantageous because it raises the average temperature of the arc, and

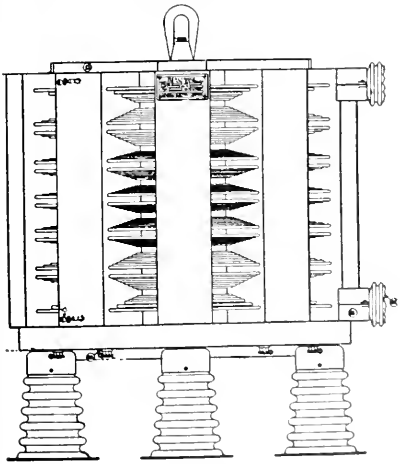


Fig. 15. Reactor

electrical operation is improved owing to the air being already in a partly ionized condition. With preheat, the velocity of the air can also be lower than when the air is cold.

The Schoenherr furnace has a preheater combined with it which takes the form of several annular tubes of steel around a central reaction chamber, and the entering cold air and the exit gases pass through these tubes in counter-current directions. As the gases leave the reaction chambers at over 1000 deg. C., it is possible to give a very high preheat to the entering air. At Saaheim, in Norway, there are 96 of these furnaces of 1000 kw., each one with its own preheater.

The Birkeland-Eyde furnace has also a preheater, because the air passes into the reaction chamber through a large number of small holes in the refractory chammotte lining. As the electric arc keeps this lining at red heat, the entering air is preheated somewhat before it strikes the arc. This lining constitutes one of the objections to this furnace, because it is expensive to build and takes several days to dry out.

In several ways it is an advantage to employ a separate preheater to serve a number of furnaces, one reason being that it can be designed efficiently to give the heat exchange. Also, hot air is always available in starting a new furnace, for when a furnace has its own preheater some time must obviously elapse before heat is available to warm up the incoming air.

It is usual to employ boilers to utilize the bulk of the heat from the furnace gases in raising steam. If the gases leave the boiler at 250 deg. C. and a further 150 deg. C. is absorbed in the preheater, then the preheater may be made of steel. At the same time it is advisable to have it in several units so as to take care of the expansion due to difference in temperature at the two ends. Thin steel tubes may be used, and the air should pass around them.

Effect of Adding Oxygen

It is of advantage to add oxygen to the air passing through the furnace, because the concentration of nitric oxide is a maximum when the product of oxygen and nitrogen is also a maximum. It can be shown that it is directly proportional to the square root of the product.

Commercially, it is only possible to add oxygen when the process is worked in a closed cycle, the amount required continuously being then only that which the nitric oxide takes up.

The oxygen does not have to be pure. Its addition to the air is equivalent to increasing its pressure, for in air it occupies only one fifth of the volume, whereas when it is equal with the nitrogen it occupies half of the volume. The effect is, therefore, the same as increasing the pressure 2½ times, because much more oxygen is passed through the furnace, yet at the same time the furnace walls do not have to withstand any extra pressure.

Effect of Increasing Pressure

It is known that increased yields can be obtained by increasing the pressure in the reaction chambers of arc furnaces, but hitherto the pressures used have been sufficient only to move the air quickly through the arc.

However, there is no need to use such "heroic" high pressures as 1500–2000 lb. per sq. in. (100–135 atmospheres) which are necessary for the Haber process of making synthetic ammonia. Also it should be remembered that air at high pressure has a greater insulating value than air at low pressure.

Absorption

Fig. 16 is a diagram indicating the approximate temperature of the gases as they pass through the system when it is desired to make nitric acid. Boilers reduce the temperature from about 1000 deg. C. to about 250 deg. C., and a heat exchanger then reduces them to about 100 deg. C. Finally, a water cooler brings them down to 40 deg. C. or lower, the final temperature obviously depending on the temperature of the cooling water; it would probably be possible in winter to reduce the temperature to about 20 deg. C. The lower the temperature of the gases in the absorption towers, the better is the absorption, and that is the reason why stronger acid is obtained in winter than in summer.

As the gases leave the furnace, they are at high temperature and must be carried in ducts lined with fire brick. Between 250 deg. and 100 deg. C. steel may be used, but below 100 deg. C. aluminum or acid-proof stoneware or silicon iron cannot be used. The water cooler should also have aluminum pipes.

Before the gas enters the towers it is necessary to facilitate the oxidation of all the nitric oxide to nitrogen dioxide, and for this purpose large open spaces are necessary through which the gases can flow sluggishly.

It is of some assistance to have connecting pipes of large cross-section. At Rjukan II, Norway, the furnaces are about 3000 feet (0.9 kilometer) from the absorption towers, and the gases are carried through an aluminum pipe about 3 ft. (0.9 m.) diameter. The gases enter the pipe at about 200 deg. C., and are cooled considerably while passing through it.

With gases at 40 deg. C. and 1.5 per cent nitric oxide concentration, the nitric acid can be easily made to about 33 per cent, which is the correct strength for the manufacture of ammonium nitrate and calcium nitrate.

When sodium nitrate is required, the gases must enter the absorption towers at about 250 deg. C., because at this temperature only about half the nitric oxide has been changed to nitrogen dioxide, and this mixture when absorbed by sodium carbonate or caustic soda gives sodium nitrite without any nitrate. For this product the absorption towers can be much smaller than those for making nitric acid, and they are also cheaper because they can be made of steel plate instead of acid-proof brick work.

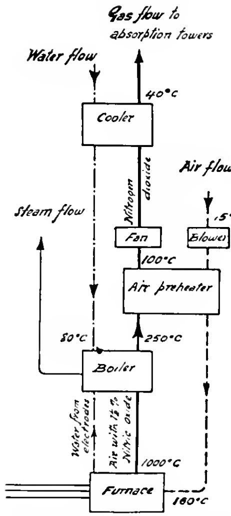


Fig. 16. Showing Flow of Gas and Air and Approximate Temperatures

Cooling the Gas

The chemical reaction of nitrogen and oxygen is reversible, but the tendency for nitric oxide gas to dissociate is only slight at below 1500 deg. C. The problem is therefore to jerk the nitric oxide from arc temperature to below 1500 deg. C. To a certain extent this is performed automatically by the air which surrounds the arc streamers, and it is probably most effective just at the moment when the arc breaks. Passing the air at high velocity through the flame is also advantageous, and at the same time the fixed gas and air should be withdrawn from the top of the furnace by an exhaust fan.

Several ways have been employed for expediting the cooling; for example, in the Pauling type of furnace some of the cooled gases are reintroduced again at a point just above the zone of maximum temperature.

Another method is to impinge the top of the arc flame onto a cooler which may take the form of a steam boiler. During experiments with an early model of the Kilburn Scott three-phase furnace, a boiler was set low enough for the electric arc flames to play against the tubes, when it was noted that they flickered about the surface much the same as do the flames of ordinary coal gas, and the boiler was not detrimentally affected. This plan takes advantage of the latent heat of steam, and the cooling is just as good in a large furnace as in a small one. The boiler or cooler is connected to earth, but as the center of the flame is the neutral point of the three-phase system no current passes, as the phases are in balance. As a matter of fact, the bulk of the electrical energy delivered to a furnace passes between the electrodes near the bottom of the flame.

Steam From Boilers

The most economical way to cool furnace gases is to pass them through boilers and to employ the steam so produced for various purposes in the factory.

In a very large installation, more steam may be generated than is required for evaporation of end products, and in that case it can be used for generating electric energy and so work regeneratively. In the latest installation at Rjukan II, in Norway, there are three 4000-kw. steam-turbine alternators supplied with steam by the hot furnace gases.

It is very significant that in an installation having practically unlimited water power steam turbines should have been installed, and indicates the saving there would be by combining an air nitrate factory with a steam power house.

The boilers may be of any pattern so long as they are gas-tight, and they may form part of the furnace, or be separate, as in Norwegian installations. The feed water should be hot so that moisture may not be deposited on the tubes, and for this purpose the water from the cooling electrodes can be used, thus giving a further saving of heat.

Theory of the Reaction

In many discussions on the subject of nitrogen fixation in arc furnaces, it has been assumed that the sole factor bringing about formation of nitric oxide is a thermal one. This is very doubtful, however, because all data relating to the laws of thermo-dynamic equilibrium have been obtained at temperatures very much lower than those commonly met with in electric furnaces; therefore it does not follow that the same laws hold good for electric furnaces.

Dr. Maxted states, in the *Proceedings of the Society of Chemical Industry* for April 15, 1918, that:

"Purely thermic interpretation of the nitrogen oxide reaction depends on a large extrapolation froml ower to higher temperatures, and assumes that no latent factors cause increase or decrease in the observed temperature coefficients."

Some experiments* by Mr. J. L. R Hayden, lead him to the conclusion that in fixing nitrogen by the electric arc the conditions of thermo-dynamic equilibrium are of secondary, if of any, moment. In other words, the process is essentially an electric one.

His experiments were made with electrodes of various material which gave different temperatures, and the order of their nitric acid production was as follows:

Concentration	Boiling Point (Arc Temperature
Iron—highest	2450 deg. C.
Titanium	2700 deg. C.
Carbon	3600 deg. C.
Copper—lowest	2310 deg. C

It will be seen that although carbon gives the highest arc temperature it is relatively inefficient in producing nitric oxide. Also the iron and copper which give approximately the same arc temperature are at opposite ends of the scale in producing oxide

Another experiment made with the mercury arc, which has a much lower temperature than the above, showed that it was easily possible to get concentrations above those representing thermo-dynamic equilibrium In electric furnaces there are other phenomena besides that of heat, for example, ionization, which appears to have the effect of disrupting the nitrogen molecules and so facilitating their combination with surrounding oxygen. It is conceivable, also, that the electric stress due to the high voltage and the magnetic field set up by the currents may have some effect.

Mr. Cramp, of Manchester, found that there was an increase of nitric oxide when ozone was added to the air passing into the arc flame, and it may be that O_3 and the corresponding polymer of nitrogen, which Sir J. J. Thompson calls N_3, are formed momentarily, and then, dissociating, the nascent atoms of oxygen and nitrogen combine.

Development in Nitric Acid Manufacture in the United States Since 1914*

By E. J. Pranke

The author furnishes figures showing that the manufacture of nitric acid in this country since the beginning of the war has increased enormously: the production from sodium nitrate has increased 630 per cent (estimated), and by next spring ammonia-oxidation plants, of which we had none prior to 1914, will furnish about 25 per cent of the total production of this acid. The greater portion of the article is devoted to a discussion of the development of these ammonia-oxidation plants and their catalizers, and in the conclusion a very favorable forecast is made of this newly adapted process for the manufacture of our nitric acid.—Editor.

The production of nitric acid in 1914, according to the census of manufacturers, was 78,589 tons of nitric acid of average strength, and 112,124 tons of mixed acid. According to other data given in the census, these figures represent about 89,000 tons of 100 per cent nitric acid. All of this acid was produced from sodium nitrate, consuming about 160,000 tons of nitrate. The pre-war importation of sodium nitrate amounted to about 560,000 tons per annum; hence the normal consumption for purposes other than the manufacture of nitric acid was about 400,000 tons.

The present rate of importation is about 1,600,000 tons of nitrate per annum. Since very little is going into storage and the total consumption for purposes other than nitric acid manufacture has increased but slightly, if at all, it may be estimated that at least 1,000,000 tons of nitrate per annum are being converted into nitric acid at the present time. This is equivalent to 650,000 tons of 100 per cent nitric acid, of which nearly five sixths is being used for the manufacture of military explosives.

Improvements in Recently Built Plants

The building of the new sodium nitrate acid plants has offered an excellent opportunity for the introduction of many improvements. The Dutch ovens under the retorts have been displaced by modern fire boxes provided with a proper arch. This change has effected a saving in coal consumption of approximately 25 per cent. The chemical stoneware from the retorts to the condensers and the glass condenser tubes have been displaced by acid-proof, high-silica iron, such as duriron and tantiron. The volvic ware saucers in the towers have also been displaced by acid-proof iron. The chemical ware from the condensers to the absorption towers, and the glass lines for circulation of acid at the sides and top of the towers, however, are retained. The absorption tower capacity has been increased about 40 per cent by the addition of more towers. Spiral rings for tower packing have taken the place of the ordinary form of packing.

Important changes have also been made in operation. The average charge of 5000 pounds of nitrate per retort has been increased to about 7500 pounds. The retorts, instead of being operated in batches, are now operated in rotation. Instead of three runs per retort per day, the usual practice is now two runs per day. The temperatures are also controlled more carefully than in the past.

The result of these improvements is an increase in the amount of nitrogen recovered as acid from an average of from about 78 to 80 per cent to about 92 to 94 per cent of the nitrogen in the sodium nitrate. At the same time the labor requirement has been somewhat decreased.

A good beginning has also been made in the recovery of nitrose gases produced in the various nitration operations. In some of the systems that have been devised, as much as one half of the fumes are being recovered. The collection of the gases from the many nitration units, however, is still a serious problem. While the aggregate amount of acid that is being recovered is large, it

* A paper read at the Fourth National Exposition of Chemical Industries, New York, September 24, 1918.

represents only a small fraction of the acid gases that are being wasted. In the ordinary nitration operation, as carried out at present, about one tenth or one twelfth of the nitric acid is wasted in the wash waters, while on an average about one eighth is lost as fumes, of which one half is recovered in plants equipped with recovery systems.

Nitric acid by direct combustion of air by the arc process has not had any important development as yet in America. Three small plants, more or less on an experimental scale, have been built in the United States and operated for short periods. The production of these plants thus far has been negligible. The total annual capacity probably does not exceed two or three thousand tons of nitric acid per annum.

Nitric acid by the oxidation of ammonia has received a considerable and important development since the outbreak of the war. In 1914, there were no ammonia oxidation plants in this country. At the present time there are under construction ammonia oxidation plants with a capacity equal to about 225,000 tons of 100 per cent nitric acid per annum.

Development of Ammonia-oxidation Plants

The first commercial-size oxidation plant was established in July, 1916, at the Ammo-Phos Works of the American Cyanamid Company at Warners, New Jersey. Six catalyzer units were installed, each with a presumed capacity of 14 pounds of nitric acid per hour. Improvements in the design of the catalyzer and in the methods of operation have brought the capacity to over 40 pounds of nitric acid per hour. The catalyzer used is a single fine platinum gauze, with an area of about two square feet, electrically heated. Over a period of two years two of these units have supplied the nitric requirements of the 60,000-ton sulphuric acid chamber plant at this works. The ammonia is taken directly from cyanamide autoclaves producing about 30 tons of ammonia gas per day, used mainly for aqua ammonia manufacture. This plant has served for several months as a training school for the instruction of operatives for the government cyanamide-nitrates plants. As an example of the normal operation of the catalyzers on ammonia taken directly from the autoclave mains, Table 1 is quoted verbatim from the records for the week, July 13 to 19, 1918. Each value is the average of determinations of two chemists working independently, with the exception of those marked (*) which are determinations of one chemist only.

TABLE 1

EFFICIENCY OF CATALYZERS IN AMMONIA OXIDATION

	Catalyzer No. 5			Catalyzer No. 6	
Date	Time	[illegible]	Date	Time	[illegible]
July 13	2:35 a.m.	96.2	July 13	5:30 a.m.	90.0
	8:40 a.m.	98.5		1:10 p.m.	93.0
	5:20 p.m.	96.[illegible]		8:40 p.m.	93.4
	11:50 p.m.	96.0	14	2:50 a.m.	93.0
14	5:50 a.m.	97.4		1:00 p.m.	94.2
	5:10 p.m.	94.8		10:15 p.m.	93.2
15	10:35 a.m.	95.0	15	8:15 a.m.	95.6
	5:15 p.m.	95.8		2:30 p.m.	90.7
16	1:50 a.m.	95.4		11:30 p.m.	92.6
	11:20 a.m.	95.4	16	8:00 a.m.	90.0
17	1:10 a.m.	92.1		8:25 p.m.	93.0*
	1:00 p.m.	92.3	17	9:30 a.m.	90.9
18	12:50 a.m.	93.4		8:20 p.m.	94.0
	10:55 a.m.	92.6	18	7:40 a.m.	92.0
	8:00 p.m.	91.9		5:10 p.m.	91.6*
19	9:50 a.m.	93.6	19	4:15 a.m.	[illegible]
	Average for the week.	94.5		Average for the week.	92.5

The cyanamide-nitrates plant at Muscle Shoals, Alabama, will use the electrically heated single-gauze catalyzer. It will produce approximately 90,000 tons of 100 per cent nitric acid per annum. The plant is expected to go into operation about November 1st. The cyanamide-nitrates plant near Cincinnati, and the one near Toledo, Ohio, will also use the same process, each producing at one half the above rate. They are expected to be in operation early next spring.

The government experimental plant at Sheffield, Alabama, known as Nitrate Plant No. 1, which will make about 15,000 tons of nitric acid per annum, has adopted a non-electrically heated multiple screen, consisting of several layers of platinum gauze, welded together at points, and rolled into the form of a cylinder. The ammonia-air mixture flows outward through the screen at a rate several times as fast as with the electrically heated single screen. After the oxidation has been started by the external application of heat, the temperature is self-sustaining from the heat of the reaction.

Consumption of Electric Energy

In view [illegible] with electrical [illegible] energy consumed, amounting to about one third of one per cent of the present market value of the nitric acid, may be regarded as negligible. As to the single versus the multiple screen, the efficiencies cited as examples of normal operation of electrically heated single screens are believed to represent the highest standards yet attained in the practical operation of ammonia catalyzers.

It is understood that the Semet Solvay Company has an ammonia oxidation plant at Syracuse, New York, using the multiple screen without electrical heating. This plant is producing several tons $NaNO_3$ per day. Information regarding efficiencies is not available.

In addition to the plants mentioned, the Navy Department decided about two months ago to build a plant at Indian Head, Maryland, for fixing nitrogen by the modified Haber Process used at Plant No. 1. All the ammonia produced will be oxidized to nitric acid, yielding about 30,000 tons per annum.

Considerable work is also being done on the use of catalyzers to hasten the conversion of the nitrose gases, obtained from the catalyzers, into nitric acid. The object is to reduce the amount of space required for reaction chambers. The experiments along this line show promise of early success.

Production Next Spring will be Nine Times Normal

The nitric acid producing rate in the spring of 1919 will be about 650,000 tons from nitrate of soda and about 225,000 tons by oxidation of ammonia obtained from the air, a total of 875,000 tons of 100 per cent nitric acid. This is about nine times the pre-war normal consumption. In 1914, the industrial explosives industry consumed about 50,000 tons per annum, while all other uses took only about 40,000 tons. The only notable increase in consuming ability since 1914, aside from military explosives, has been in the dye industry. In 1917, it was estimated that 30,000 tons of dyes were produced in America, equal to the total 1914 consumption. The production will probably increase somewhat further, but at most could hardly consume more than 30,000 or 40,000 tons of concentrated nitric acid. With a producing rate of 875,000 tons, and a consuming ability in peace times of 125,000 tons, or possibly 150,000 tons, it is evident that over four fifths of the nitric acid producing capacity will have to be shut down as soon as peace conditions are established.

Ammonia-oxidation Method may be Principal Source

The successful development of the ammonia oxidation process raises the question whether this may not become the principal source of nitric acid in the future. While a categorical statement cannot be made, some of the major factors may at least be pointed out. The cost of converting sodium nitrate to concentrated nitric acid is just about equal to the cost of converting autoclave ammonia gas to concentrated nitric acid, interest and depreciation included in both cases. Ammonia gas, however, is a cheaper form of nitrogen than is nitrate of soda. It is cheaper by the amount of sulphuric acid required to fix the ammonia gas in the form of ammonium sulphate, for sodium nitrate and ammonium sulphate in the past have always sold at about the same price per pound of nitrogen. They will probably be sold on a competitive basis after the war, or if there is any difference the ammonium form will probably be the cheaper. The differential between ammonia gas and ammonium sulphate, then, will make a difference of about 15 to 20 per cent in the cost of nitric acid in favor of ammonia oxidation. The fact that the sodium nitrate acid plants are being amortized during the war and are conveniently located for peace-time industrial uses, while new ammonia oxidation plants would have to be built at these same points in order to avoid transporting acid, is relatively not very important, because the interest and depreciation charge saved by amortization of the sodium nitrate acid plants is only about 4 per cent of the normal cost of the acid. The decisive factor will probably be simply the question of whether the difference in cost of acid by the two processes is a sufficient incentive to overcome the inertia of human nature against changing existing practices.

Starting and Stability Phenomena of Ammonia Oxidation and Similar Reactions*

By F. G. Liljenroth

The fundamental characteristics of catalytic exothermic gas reactions are explained in this article by means of a method analogous to the method of investigation generally adopted by electrical engineers in connection with electric dynamos. Exactly as the saturation curve and the field-resistance line simply and clearly explain and determine the properties of an electric dynamo, the conversion curve and the heat-of-reaction line serve to explain and determine the characteristics of a catalytic burner. In the same manner as a shunt-wound, direct-current generator is able to build up its voltage only if the saturation curve lies above the field-resistance line, a catalytic burner is self-starting only in case the conversion curve lies above the heat-of-reaction line. The stability of a catalytic burner is affected by variations in the gas velocity in the same way as the stability of a direct-current generator is affected by changes in the speed. If the speed drops below a certain value, the generator loses its voltage; if the gas velocity falls below a certain value, the catalytic burner goes out.—Editor.

If the temperature of the gauze or catalyst of an ammonia oxidation burner is varied, but all other conditions such as mass flow, gas composition, etc., are maintained constant, the percentage conversion or the degree of reaction will in principle vary according to the curve shown in Fig. 1. At low temperatures there will be practically no nitric oxide formed, but at a certain temperature the conversion will begin to increase very rapidly because the reaction velocity is highly dependent upon the temperature. At still higher temperatures the ammonia will begin to decompose into its elements, and the rate at which the conversion increases will be lower; or in other

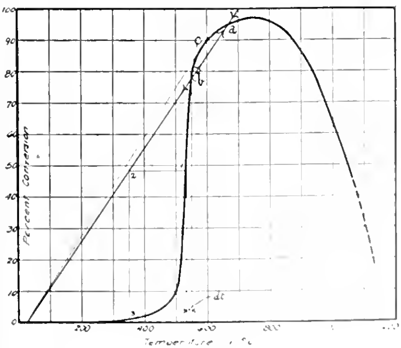


Fig. 1

words, the shape of the "conversion curve" will change from convex to concave, and at a certain temperature which the writer understands is somewhere around 750 deg. C., the conversion will reach a maximum of nearly 100 per cent. Thereafter, the conversion will again decrease and reach a zero value at a fairly high temperature.

The heat of reaction within the temperature limits in question is practically constant and equals about 53,000 gram calories for each gram molecule of nitric oxide formed. If we assume a 100 per cent conversion and the presence of, for instance, 9 molecules of air for each molecule of ammonia in the initial gas mixture, then the temperature rise of the gas current due to the heat of reaction will be equal to $\frac{0.95 \times 53{,}000}{7.4\,(9+1)}$ of 675 deg. C., assuming 5 per cent heat losses by radiation or convection. If the temperature of the ingoing gas is 25 deg. C., then the temperature at the gauze will be 700 deg. C. The figure 7.4 represents the average molecular heat capacity of the gas mixture at constant pressure. As the gas mixture consists principally of diatomic gases and as the temperature range is comparatively small, it is readily seen that this quantity is practically independent both of the conversion percentage and of the temperature, and that it can with great accuracy be put equal to 7.4.

If the ammonia content in the initial gas mixture is maintained constant, the temperature rise due to the heat of reaction will increase in proportion to the conversion and the temperature of the gauze is graphically represented by the straight line in Fig. 1. This line refers to an initial gas composition of 9 to 1 and to a temperature of the ingoing gas of 25 deg. C. To any other gas composition and to any other temperature of the ingoing gas there corresponds another line. Particular attention is called to the fact that, in order not to complicate the problem, the heat of reaction due to the dissociation of ammonia into its elements and other secondary reactions, which take place principally

*From *Chemical and Metallurgical Engineering*, Sept. 15, 1918.

at the descending part of the conversion curve, have been deliberately disregarded. Such a first approximation is permissible because the losses are in any case small.

General Conditions of Stability

The straight line, which will be called the "heat-of-reaction line," cuts the "conversion curve" ordinarily at two points, *a* and *b*, Fig. 1. It seems, therefore, as if it would be possible to have two points of operation for any burner at a given gas composition and gas flow. But a closer investigation shows that the reaction cannot be maintained at the point *b* because the conditions for stability at this point are not fulfilled. Suppose that the burner is working at this point and that for some reason the temperature decreases by the small amount of *dt*. Then the conversion will decrease to point *1*. This decrease will cause the temperature to be lowered still more, to point *2*, and this will in turn cause a new decrease in the conversion, to point *3*, and so on. In other words, the burner will go out.

If we assume that for some reason the temperature increases, it will in the same way be found that even in this case we will move away from the point of intersection, which is indicated in the illustration by the arrows pointing apart from this point.

If we treat the other point of intersection similarly (point *a*), it will be found that conditions are just opposite. If for some reason we depart from the point, we will immediately be carried back to it, which fact is indicated by two arrows, both pointing toward the point. Point *b* is therefore an unstable location while point *a* is a stable one. As can easily be understood, this characteristic difference depends upon the manner in which the heat-of-reaction line cuts the conversion curve. In order to obtain stability, the heat-of-reaction line must cut the conversion curve from below, and from this it follows that the part of the conversion curve to the left of the tangential point *c* is unstable, but that the part to the right is stable. It will also be understood that the stability or unstability increases with increase in the size of the angle at which the line and the curve cut each other.

Starting of the Reaction

From what has been said regarding the unstability of the point *b*, we can now understand that the ammonia oxidation process is not self-starting or self-exciting, but that the gas, in order that the reaction may be started, must be heated by a flame or by electricity to at least such a temperature *T* that the resulting line becomes a tangent to the ascending part of the conversion curve, as is shown in Fig. 2. In such a case the reaction will start and after a short time arrive at point *e*. After this the starting flame can be removed and the reaction will move to point *a*. This not only makes it very clear whether and why the ammonia oxidation or any other continuously operated catalytic reaction is self-starting or not, but it also gives us a method by which to predetermine the temperature *T* which is necessary to start the reaction. This "ignition temperature," as seen from Fig. 2, is always much lower than the reaction temperature; or, in other words, it is not necessary to heat the reaction to its full temperature but only to help it to overcome the obstacle formed by the ascending part of the curve. When this obstacle has been overcome, the reaction will take care of itself and work up to the full temperature.

The temperature necessary to start the reaction can be decreased by using a gas mixture richer in ammonia, because the position of the heat-of-reaction line will be lowered. This is indicated by the lines *fk*

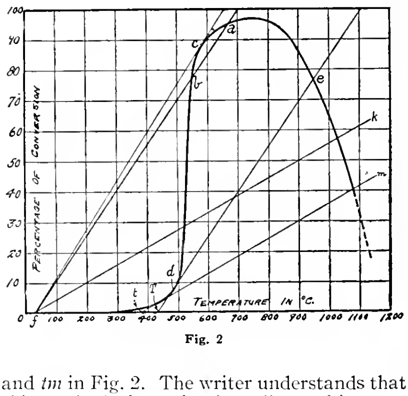


Fig. 2

and *tm* in Fig. 2. The writer understands that this method of starting is really used in some oxidation plants.

The shape of the conversion curve of all continuously operated exothermic catalytic reactions is in principle the same as that of the ammonia oxidation. It ascends at first, due to the fact that the reaction velocity increases with the temperature, but as it is limited by the always descending equilibrium curve, it must sooner or later reach a maximum; thereafter it begins to descend. (In the ammonia oxidation process the descent begins earlier than would be expected from the equilibrium curve,* this being due to the fact that another reaction, the decomposition of ammonia into its elements, begins to take place at higher temperatures beside the oxidation reaction.) The possibility that there are continuous exothermic reactions which are self-starting is therefore not excluded, because the only condition that needs to be fulfilled is the necessity of having the conversion curve from the beginning lie above the heat-of-reaction line.

An example of a self-starting reaction is offered by the long known fact that the hydrogen air or hydrogen oxygen flame can be ignited by means of a small piece of platinum sponge. This is represented in principle in Fig. 3. The lower curve corresponds to the non-catalytic reaction which, as may be noted, is not self-starting. By using a strong catalyst the curve is raised so that from room temperature and up it lies above the heat of reaction line, this being the general condition for self-excitation. The temperature of the platinum sponge will

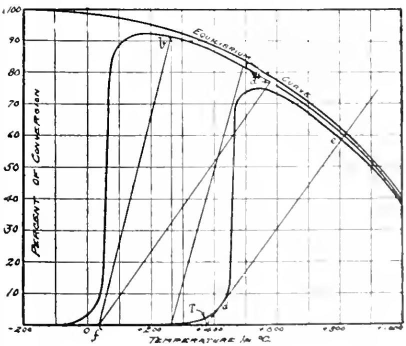


Fig. 3

consequently increase to the point *a* which is always above the ignition temperature *T* of the non-catalytic reaction. The fact that a hydrogen flame can be ignited by means of spongy platinum induced inventors to try the same experiment with ordinary coal gas. It was found, however, that the platinum sponge began to glow but that the gas would not ignite. This was explained by saying that coal gas is not so inflammable as hydrogen and that the temperature of the platinum sponge was too low.

How can this fact now be brought into agreement with our theory? The explanation is very simple. The radiation of the ignition system is very large, even if the radiation of the whole system is zero, and to the ignition conversion curve (the upper curve) belongs, therefore, not the same heat-of-reaction line as to the main conversion curve, but a line much farther to the left. If the point of intersection *b* between this line and the catalytic conversion curve corresponds to a lower temperature than *T*, it can be seen that the platinum sponge will begin to develop heat without being able to ignite the gas. In order to raise the temperature to *T*, we can place two pieces of platinum sponge in series so that the gas arrives at the second one preheated to such a temperature that the final temperature is higher than *T*. If it is not enough with two, we can put three pieces in series.

Numerous other arrangements have been proposed in order to ignite the coal gas flame by means of platinum sponge, and the reasons why one arrangement works better than another, or why it does not work at all, are very vaguely stated in the literature, but with this explanation become extremely clear and simple.

Determination of the Conversion Curve

The heat-of-reaction line can be very easily determined both theoretically and experimentally, but the conversion curve can be determined only by experiments. Points on the descending part to the right of point *a* (Fig. 2) can be determined by preheating the ingoing gas to different temperatures; at the same time we can also obtain the part of the curve which is to the left of point *d*. The part of the curve between *a* and [illegible] can be determined by increasing the heat losses, for instance by water cooling the burner. The unstable part of the curve between points [illegible] and *d* cannot be determined directly, but it can be determined indirectly by extending the stable parts of the curve and connecting [illegible] and [illegible] in an intelligent way. In case the temperature caused by the heat of reaction is small, which for instance is the

* It can easily be shown by Nernst's "New [illegible] the ammonia nitric oxide equilibrium is [illegible] limits in question, practically constant [illegible] For obvious reasons this equilibrium [illegible] experimentally.

case in the Haber process (due to both the low heat of reaction and the low conversion obtained), the unstable part of the conversion curve will be very short. Practically the whole conversion curve can be determined therefore simply by cutting out the heat exchanger and heating the gas electrically, keeping a constant current or voltage.

Practical Conditions of Stability

It has been noted that the only condition which needs to be fulfilled in order to keep a reaction going, when it once has been started, is the necessity of having the heat-of-reaction line cut the conversion curve from below. We would expect therefore that it should be possible to work at the maximum point of the conversion curve because this point is on the right side of point *c* where the stability zone begins (Fig. 2). This also is possible under ideal conditions, that is, if gas composition, gas flow, etc., are maintained absolutely constant. In practice, however, there will always be small variations in gas composition and gas velocity which cause the heat-of-reaction line and the conversion curve to change their positions continuously. If, for instance, the ammonia content in the ingoing gas for some reason decreases, the heat-of-reaction line will turn counter-clockwise around its point *f* on the abscissa. If it turns past the tangential position *c* and remains there long enough for the gauze to cool below the ignition temperature, the burner will go out. This time which, by the way, can be calculated exactly if the conversion curve is known, is very short because the gauze is rapidly cooled by the incoming cold gas mixture, the heat capacity of the gauze and the walls being comparatively small.

The conversion curve is also affected by the gas composition and besides that by the gas velocity. As already noted, both of these quantities vary in practice a few per cent and consequently the heat-of-reaction line and the conversion curve will both oscillate around an average position. Ample margin between points *a* and *c* must therefore be provided. If the top of the conversion curve is sharp it will be impossible to work at a maximum efficiency, because we have to move the working point farther to the right side, sacrificing efficiency in order to obtain stability. This also implies higher temperature. If the conversion curve is very flat, which seems to be the case in the ammonia oxidation reaction, it will be possible to work not only at the top point but even a little to the left of it. As far as the writer understands, this is really what is done in the ammonia oxidation process if no heat exchanger nor any additional heat above the heat of reaction is used. A decrease in the radiation losses will consequently improve not only the stability but also the efficiency. If the radiation is decreased as much as possible, and if we are still on the ascending part of the conversion curve, the only way to reach the top is to use a heat exchanger or some additional heat. If we are very near the top it will probably not pay to go into this complication.

The margin of stability must be greater, the greater the variations in initial gas strength and gas velocity. It is, therefore, of importance to keep the motors at a constant speed driving the ammonia and air blowers and in general to keep the gas current as steady as possible. Of how great importance this is can be determined only if conversion curves of a number of different gas compositions and different gas velocities are known.

Influence of Catalytic Poisons Upon Stability

If occasionally the steadily flowing gas current should carry along some foreign gas, we should have the same kind of disturbance as we should if the ammonia content varied. If the foreign gas or matter is not indifferent or if it acts as a poison to the catalyst, the disturbances may be still worse. In such cases still more margin must be provided; that is, we must work farther to the right of the maximum point (Fig. 4) which means a higher temperature and a decrease in the conversion from point *a* to, for instance, point *g*. We must now remember that the conversion curves always refer to absolutely pure gas mixtures and we shall have therefore in addition to this decrease another reduction depending upon the frequency, the nature, and the duration of the impurities.

This can be stated also in another way. In a plant where such impurities are likely to appear, we must safeguard ourselves against the burner going out by working with more ample margin; that is, even if for some length of time the gas happens to be pure, we will still have a lower efficiency than in a plant where we know the gas mixture to be constantly pure. When the impurities appear, however, we shall have an additional loss, but the loss cannot, of course, be precalculated but only estimated from practical experience.

The first kind of loss can be measured exactly by running the burner with pure ammonia at the same gas flow and gas strength as when the impure ammonia is used. It can also be determined from the conversion curve in the following way: Suppose the gauze is heated by electrical energy but that no heat exchanger is used, and furthermore that the electrical power consumed is equal to 0.03 kw-yr. per ton of HNO_3 which equals $\frac{0.03\times 8760\times 3600}{4.2}$ kg. cal. per ton of HNO_3, which in turn equals $\frac{0.03\times 8760\times 3600}{4.2}\times\frac{63}{1000}$ or 14,000 kg. cal. per kg. mol. of NH_3.

The temperature rise due to the electrical heating alone will hence be $\frac{14,000}{7.4(9+1)}$ or 190 deg. C. If this temperature is added to the plain heat-of-reaction line, we get a line (*hg*, Fig. 4) beginning at 190+25 deg. C., and ending at 700+190 deg. C. This line cuts the conversion curve at point *g* and we can thus find the conversion and the loss. The temperature rise of 190 deg. C., due to the electrical heating, could also have been determined experimentally by running the burner with normal gas flow and normal electrical energy but without igniting the burner. This test can be run just as well with ordinary air as with ammonia-air mixture, thereby saving the ammonia.

In the ammonia-oxidation process it happens that if the radiation losses are small, the reaction itself develops just about enough heat to give the proper temperature, or in other words, the heat-of-reaction line cuts the best conversion curve in the neighborhood of the top just far enough to the right of the point *c* to secure stability, assuming that pure raw materials (for instance, high-grade, coke-oven aqua ammonia) are used. In case the ammonia contains impurities, poisonous to the catalyst, as seems to be the case with cyanamide ammonia, higher temperatures must be employed in order to secure stability, as has been shown above. This can be done either by using a heat exchanger, line *fg* (Fig. 4), or by supplying some additional heat, line *hg* (Fig. 4). As there is always a time lag in the action of any heat exchanger the temperature will not decrease instantaneously as the impurities come along. If, therefore, the impurities are of short duration with fairly long intervals, the use of a heat exchanger may be preferable to the plain heat-of-reaction method, assuming that it could be employed here. If, on the other hand, the impurity periods are long and the intervals short, it will be understood that the heat exchanger is inferior to the plain heat-of-reaction method.

This is a true analogy to the action of a flywheel in connection, for instance, with a

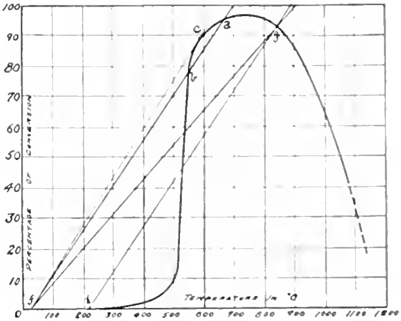


Fig. 4

rolling mill. In a blooming mill very heavy flywheels are used, whereas in a wire mill the rotating masses must be made as small as possible. The employment of additional heat, either by preheating the gases in a fuel-heated furnace or by electrically heating the gauze, gives the most stable conditions, especially if the external heat alone gives a temperature which is higher than the ignition temperature, in which case the burner ignites itself again as soon as the impurities have passed, supposing that these were of such magnitude as to cause the burner to go out. It is not very probable that this is the case in any ammonia burner because it would mean unnecessarily high starting, very high temperature, and very low efficiency. On the contrary, even electrically or fuel-heated burners must be ignited by a flame or coil or by increasing the current in the gauze above the normal value.

In regard to fuel heating versus direct electrical heating of the gauze, we would expect one method to be just as good as the other, assuming that the electric current has no direct activating influence on the platinum.

Such an influence is very improbable in view of the excellent results obtained without the use of electrical heating. This has probably been adhered to as an easy way of explaining the fact that the direct electric heating gives higher stability than if the same amount of additional heat is supplied outside the gauze. The following explanation seems to the writer to be much more plausible. The electrical resistance of platinum as well as of other metals increases with the temperature. At 700 deg. C. it is about three to four times as high as at 0 deg. If, therefore, due to a weakening of the gas strength or to poisonous impurities, the gauze begins to cool and blacken, the current flowing through it will immediately increase in the same proportion as the resistance decreases. Furthermore, as the heat developed is proportional to the square of the current times the resistance (I^2R), it follows that the electric energy converted into heat will increase when the temperature decreases. This phenomenon is the more marked the less external electric resistance there is connected in series with the gauze. If the external resistance is equal to or higher than the internal, the reverse condition will prevail and it may be necessary to use an automatic constant-current regulator. If none or only a very small amount of external resistance is used, it is not only useless but detrimental to use automatic regulation. Further investigation of this problem leads to very interesting conclusions in regard to the manufacture of the gauze and the arrangement of the electrical heating and starting. Besides this "electrical influence," the electric heating has the advantage of having the heat supplied directly within the metal, whereas with outside heating the heat must first travel from the gas to the metal.

It has been noted that when using even pure raw materials ample margin of stability must be provided to take care of the oscillations in the heat-of-reaction line and in the conversion curve, because of variations in the gas strength and gas velocity. We will discuss this matter more in detail.

Influence of Gas Velocity

The gas velocity has no influence upon the heat-of-reaction line but affects the conversion curve in the following manner: At low temperatures, where practically no ammonia dissociation takes place, the conversion is higher the lower the gas velocity, because the time of reaction is longer and the reaction consequently comes closer to equilibrium. At higher temperatures this increase is probably more than counterbalanced by the increase in ammonia dissociation due to the same conditions as the increase in the ammonia oxidation. If, therefore, the velocity corresponding to our working curve is called 100 per cent, the curves corresponding to 90 per cent and 110 per cent will probably have the positions and shapes indicated in Fig. 5.

It can be easily seen why the stability decreases when the gas velocity increases and why the flame can be "blown out." If the velocity decreases, the stability will at first increase, but probably decrease later on. If this were not the case, it would be possible to get the reaction to start without the use of an ignition flame simply by increasing the gas velocity very slowly from zero up.

As seen, the 110 per cent curve is shown having a higher peak than the 100 per cent curve. If this really is the case, there is a double reason why we should increase the working velocity and at the same time increase the temperature by, for instance, introducing a heat exchanger. The output of the plant will increase not only in proportion to the gas velocity but also in proportion to the conversion. If we increase only the gas velocity without changing the heat-of-reaction line the conversion will go down, probably more rapidly than the velocity will go up, resulting in a lower output instead of a higher one. Besides this the stability will rapidly decrease, as already noted.

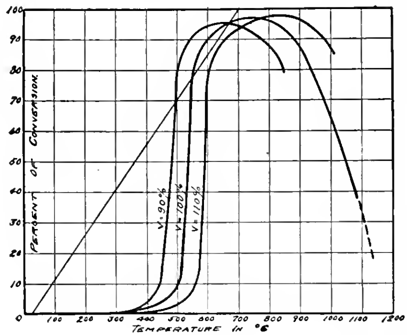


Fig. 5

Influence of Gas Strength

The influence of the variations in the ammonia content of the gas mixture upon the stability is more complicated because such variations influence both the heat-of-reaction line and the conversion curve. This first influence is very simple; the heat-of-reaction temperature at a certain conversion increases in proportion to the ammonia content (Fig. 6). The latter influence, however, is very complicated and the only guess the writer would like to make is that at lower temperatures the conversion increases with the gas strength. If the curves for different gas strengths appear as is indicated in Fig. 6, we can understand that the stability will be greatly increased if the gas strength increases, because the heat-of-reaction line moves to the right and the conversion curve to the left. Conversely, the stability will rapidly decrease when the gas strength is weakened.

What has been said regarding the possibility of improving the process by decreasing the time of reaction and by introducing at the same time a heat exchanger can also be applied here if we substitute gas strength for time of reaction and assume that the conversion curve in principle moves as indicated in Fig. 6.

If the curve, on the contrary, moves to the right instead of to the left when the gas strength increases, the stability will be practically unaffected by changes in the gas strength, because the heat-of-reaction line will oscillate synchronously with the conversion curve.

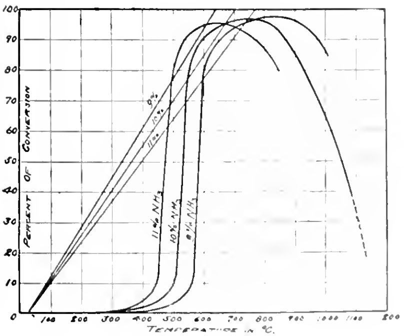


Fig. 6

Oxygen Instead of Air

If the ammonia gas is mixed with oxygen instead of with air we must for economical reasons work with a very high ammonia content in the ingoing gas. The heat-of-reaction line will consequently turn clockwise a very big angle, giving a temperature several times higher than that when using air at the same conversion. If the conversion curve has the shape assumed, and if this shape is not materially changed by the exclusion of the nitrogen, the result will be a higher temperature and stability, but a lower efficiency than if air were used. This can, of course, be corrected by water cooling the gauze, but as when using air, the stability is sufficient and the efficiency above 95 per cent, the use of oxygen is not justified, at least not for the sake of a possible increase of efficiency.

Thickness and Number of Gauzes

In view of what has been said, the influence of the thickness and number of gauzes becomes very simple and clear.

The thickness of the gauze affects the conditions only in the matter of reaction time, assuming that the effective contact surface is changing in the same proportion as the contact time. A change of the thickness of the gauze, therefore, acts in the same way as a change in the gas flow. The result will be the same whether we double the gas flow, or decrease the thickness of the gauze to one half. If the gas flow and the thickness of the gauze are both increased or both decreased in the same proportion, the conditions will not be changed at all.

The influence of the number of gauzes is the same as the influence of the thickness of the gauze, but only if the gauzes are placed very near each other and in good metallic connection so that the temperature is always the same in all the gauzes.

The problem is quite different and much more complicated if the thermal interconnection of the gauzes is incomplete. In order not to make the problem too complicated, we will assume the extreme condition that the gauzes are completely independent of each other thermally. This means that no other heat exchange can take place between the gauzes than by the way of the gas current. Let us assume that we have a burner working with, for instance, two gauzes placed in complete contact with each other. If, now, the two gauzes are moved apart and thermally isolated from each other so that no heat can be radiated or conducted between them, the first gauze will act as if the velocity had been increased to double its value. If, before moving the gauzes apart we were working in the neighborhood of the top of the conversion curve, the burner would probably go out, or at least work with less margin of stability. If the latter is the case, the temperature will change somewhat but the efficiency will still be in the neighborhood of its maximum value, leaving practically nothing for the second gauze to do. If the burner goes out we have to use a heat exchanger or apply electric heating, or we have to decrease the gas flow in order to re-establish the stability. If we apply any of these means just sufficiently to get the same stability and efficiency as before, there will again be practically no work left to the second gauze. But even if we use these means in excess, or in other words, when we work far down on the descending part of the conversion curve, the second gauze will have very little to do because the losses in the first gauze are principally caused by ammonia decomposition. Only in case we work far down on the ascending part of the conversion curve would there be some ammonia left for the second gauze, but as previously shown, the ascending part of the conversion curve is practically all within the unstable zone. If this could in some way be made stable, the gas leaving the first gauze would have to be water-cooled before it entered the second gauze in order to prevent the latter from reaching too high a temperature and too low a yield.

In case platinum should become very scarce, such an arrangement might be advantageously used, in that a cheap, low-grade catalyst could be substituted for the first gauze and the succeeding platinum gauze made to do the final work analogous to the method frequently used in the catalytic sulphuric acid process. But the first stage of the conversion must be worked in such a way that the greater losses will consist principally of ammonia going unchanged through the catalyst; that is, we must work in the unstable zone, which might not be absolutely impossible.

Synthetic Ammonia Process

Here the conditions are still simpler because no disturbing reactions take place. The conversion curve has the same shape as in the ammonia oxidation process. It first rises rapidly, reaches a maximum, and then begins to decrease because the conversion is limited by the falling equilibrium curve. If the gas velocity is decreased, the entire curve moves upward, and vice versa if the velocity is increased (Fig. 7).

It seems, therefore, as if we ought to work with a very low gas velocity. This would be true if the conversion were the deciding factor, but because of the fact that the gas mixture is recirculated, the conversion is of only secondary importance. The deciding factor is the output, which is the product of gas velocity and conversion. The working point is therefore the top of the conversion curve at which this product is at a maximum. If, however, proper consideration is given to the cost of the ammonia removal and to the cost of the electric power, a new curve somewhat above this curve is obtained. Anyhow, we will assume that the curve marked velocity 100 per cent is the most economical curve.

The heat of reaction is equal to about 14,500 g. cal. per g. mol. of ammonia at the temperatures in question. For each per cent of conversion, the corresponding temperature rise is thus equal to $\frac{14,500}{7.25 \times 2 \times 100}$ or about 10 deg. C.

The corresponding heat-of-reaction line never cuts the conversion curve, which means that in the synthetic ammonia process, contrary to what is the case in the ammonia oxidation process, a heat exchanger must always be used. Besides the heat exchanger, there must usually be supplied some additional (frequently electric) heat. The reason for this is that the heat of reaction is as a rule insufficient to cover the radiation loss and to create the temperature difference

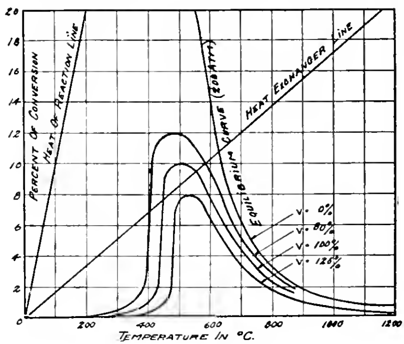


Fig. 7

which is needed to keep the size of the heat exchanger within reasonable limits. If a high pressure and a good catalyst are used the conversion will be higher, the heat of reaction will be sufficient, and no electric or other heat needs to be supplied from without except during the starting period, as can be seen from Fig. 7. The amount of electric power necessary for starting can easily be calculated if the conversion curve and the gas velocity are known. This power can be decreased if the gas velocity is lowered during the starting period, as seen from Fig. 7. It can also be noted that if the gas velocity is increased, the stability will decrease and vice versa. Ample margin of stability, therefore, must be provided; if the gas velocity is increased too much, the flame can be "blown out."

If no electric heat is used, the influence of the gas velocity on the heat-of-reaction line ought to be very small, because at the high mass flow per square foot here prevalent, the heat transfer (B.t.u. per sq. ft. per hour) of the heat exchanger walls is practically proportional to the gas velocity. The heat transfer is equal to the sum of two quantities, one of which is constant and the other proportional to the mass flow per square foot. If the mass flow per square foot is very large, as is the case here due to the high compression (100 to 200 atm. pressure) the constant quantity is negligible. If, after all, there is an influence depending upon a faulty design of the heat exchanger, this influence works to turn the heat-of-reaction line counterclockwise when the velocity increases. As shown above, the conversion curve moves in the opposite direction. In such a case a still greater margin must be provided.

If electric heating is used but no heat exchanger, the resulting line is parallel to the heat-of-reaction line proper, and if a heat exchanger but no electric heating is used the resulting line goes through the origin. Consequently, if both electric heating and a heat converter are used simultaneously, the resulting line is the sum of these two factors. If the gas velocity increases, the constant part of the temperature corresponding to the electric power decreases inversely as the gas velocity. Strange as it may sound, the reaction is therefore more sensitive for increases in gas velocity with electric heating than with only a heat exchanger.

The gas composition has no influence at all upon the heat-of-reaction line and practically no influence upon the conversion curve, which can be understood from the following. The conversion corresponding to equilibrium is approximately proportional to $\sqrt{NH^3}$, where H is the volume of hydrogen and N the volume of nitrogen present in a certain amount, say four volumes, of the mixture. If we are far from the point of equilibrium, the decomposition velocity is negligible and the conversion is consequently in proportion to H^3N. The following tabulation shows that both $H^3 \times N$ and $\sqrt{H^3 \times N}$ are practically constants within wide limits:

H	N	$H^3 \times N$	$\sqrt{H^3 \times N}$
3.2	0.8	26.3	5.14
3.1	0.9	26.8	5.17
3.0	1.0	27.0	5.20
2.9	1.1	26.8	5.17
2.8	1.2	26.3	5.14

The gas composition, therefore, has practically no influence upon the stability.

Conclusion

In the same manner, many interesting conclusions can be drawn in regard to the starting and stability of other continuously working catalytic and exothermic reactions as, for instance, the sulphuric acid process, the conversion of $CO+H_2O$ to CO_2+H_2, the conversion of NO to NO_2, etc.

The method can probably be advantageously applied also to noncatalytic, exothermic, continuous or discontinuous (explosive) reactions, although the conditions here are much more complicated because the time of reaction in the first case is not an arbitrary constant but a function of the temperature, the gas velocity, the radiation, etc. In the second case, the time of reaction is in itself an independent variable in addition to the independent variable which we already have, namely, the temperature.

It would be beyond the scope of this article to go into these questions, but the writer hopes that the above examples have been sufficient to demonstrate the usefulness of the method of investigation set forth. It not only explains in a very simple manner the starting and stability phenomena and the influence of catalytic poisons on the stability, but it might also be useful for the further studying and improving of ammonia oxidation and similar processes. It is, therefore, desirable that pure raw material conversion curves be determined for different gas strengths and gas velocities, both for ammonia-air and ammonia-oxygen mixtures. If such curves were available, it would be possible to adjust or design a burner for a maximum commercial efficiency, giving proper consideration to conversion efficiency, output, etc. This applies also to other processes.

Finally, the writer wishes to point out that this article refers only to the method of investigation and not to any specific data. The shape of the curves and the figures given should be considered only as examples.

Better Frequency Control

By Henry E. Warren

President Warren Clock Company, Ashland, Mass.

The device described in this article for the control of frequency bears the same relation to the usual frequency indicator that the recording wattmeter bears to the indicating wattmeter. The indicating instruments show only the instantaneous values and take no account of the mean value. A steam engine governor is adjusted to permit a definite number of engine revolutions per day, the numerous small periods of higher speed than normal being balanced by corresponding periods of lower speed. The Warren method of frequency control, as it were, records these revolutions, and hence indicates the mean frequency and enables the operator to adjust the governor regulating mechanism to maintain the average frequency at its normal value practically exact.—Editor.

As everybody knows, the ordinary method of measuring frequency is by means of a meter which indicates upon a scale the value at any instant. Such a meter, under observation by a switchboard operator, serves to establish the speed of the tubines, which is regulated through the electric speed controllers of the governors manipulated from the switchboard. This common method of regulation has certain faults which hitherto have not been emphasized because they have not been obvious, and also because there has been no better way of accomplishing the regulation. These faults may be summarized as follows:

1. A frequency meter indicates only the instantaneous value. This is continually varying above or below the average value, owing to sudden load changes and corresponding governor action. When the operator looks at the meter the frequency may be momentarily high or low, but he has no means of knowing that the error is only momentary, and consequently he makes an adjustment of the speed, which of course alters its average value. If the average value was correct before, he has now made it incorrect. A few minutes later, another observation of the meter, based again upon a momentary condition, may result in another alteration of the average speed. The larger the power station and the smaller the load fluctuations, the smaller will be the deviations of the frequency from its average value; but in any case, each correction of the turbine speed made by the operator will be uncertain in its effect to an extent measured by the momentary fluctuations in frequency. It will be seen that a large proportion of the speed adjustments that are made are unnecessary or worse. Moreover, in order to secure tolerable results, frequent adjustments must be made; otherwise the average speed will be away from its normal value for considerable periods of time.

2. All common types of frequency meters are subject to errors of significant value. These errors may be due to calibration or to the effect of time and use upon the instrument itself; or they may depend upon temperature changes. Frequent recalibration may reduce the former kinds of error, but those effects which are due to temperature are almost invariably overlooked. As a consequence of these instrumental errors, it is probably not rash to say that the average frequency of most power systems is not within 1 or 2 per cent of its assumed value. It is a fact that the frequency of any system varies with the temperature at the switchboard where the frequency meter is located, and this variation is by no means insignificant.

3. The precision in maintaining the average speed which can be secured by any ordinary frequency meter, even ignoring errors due to calibration or temperature coefficient, is of course limited by the size of the scale graduations and the probable reading error of the observer. With ordinary commercial instruments it is scarcely possible to read closer than one tenth cycle on a 60-cycle scale, which represents a precision of one sixth of 1 per cent. This is, of course, far smaller than would be significant for the ordinary requirements of today; but for the use of the new devices which are mentioned hereafter, such an error in the average frequency would be serious.

An Improved Method

The new method of maintaining frequency which has been in actual use during the past two years by a few of the largest power companies in New England and New York City, differs radically from the conventional plan. No frequency meter of the ordinary type is required. Instead, a device which conveniently and accurately compares the integrated alternations with elapsed time serves as a guide to the operator for adjusting the speed of the turbines. This device is comparatively insensitive to the instantaneous value of the frequency, but shows its average value with the very greatest precision.

The instrument itself, which is known as the Warren master clock, is shown in Fig. 1. It consists of a complete pendulum clock with two dials. The lower one, which is of no particular importance for this purpose, serves merely to indicate the time of day in the conventional manner. The upper dial, of larger diameter, has a hand which revolves once in five minutes. The clock movement is provided with novel electrical means for regulating the rate with very great precision. The pendulum rod is made of "invar," so that the clock is practically unaffected by temperature changes. It is an extremely accurate timekeeper, and can be regulated to run with an error not greater than a second or two per week.

Mounted upon the upper five-minute dial of this clock is another hand which is gold-colored to distinguish it from the black clock hand. This gold hand is wholly independent of the clock movement, but is driven through gearing by a small self-starting synchronous motor, illustrated in Fig. 2. This motor is connected permanently through any convenient potential transformer to the alternating current system. The gear ratio between the gold hand and the motor is such that at normal frequency, for example 60 cycles, the hand will revolve once in exactly five minutes. Incidentally the synchronous motor keeps the pendulum clock movement constantly wound at uniform tension.

After the Warren master clock has been started and regulated, the gold and black hands on the five-minute dial are set over each other, and the operators are instructed to adjust the speed control switches of the turbines occasionally, if they observe any tendency of the gold hand to gain or lose with respect to the black hand.

It is surprising to observe how slowly these two hands change their relative positions, after the speed of the turbines has been correctly adjusted. This is because the turbine governors maintain the average speed very accurately indeed, and the momentary fluctuations in speed, which are just as likely to be above as below the average value, cancel out and do not perceptibly affect the relative position of the two hands. In other words, the clock gives a true indication of the average value of the speed. It serves therefore to establish a correct base line for the frequency. Inasmuch as it does not respond visibly to the momentary fluctuations, the operator is not invited to make unnecessary corrections of the speed, and the labor for him is very materially lessened.

A Comparison of Results

We will now compare the results obtained by the new method with those by the conventional method.

1. From the standpoint of the operator there is a considerable advantage in eliminating unnecessary and objectionable manipulation of the speed-control devices in a continual effort to follow fluctuations in speed which are only momentary. This gain means an appreciable saving in labor and mental effort.

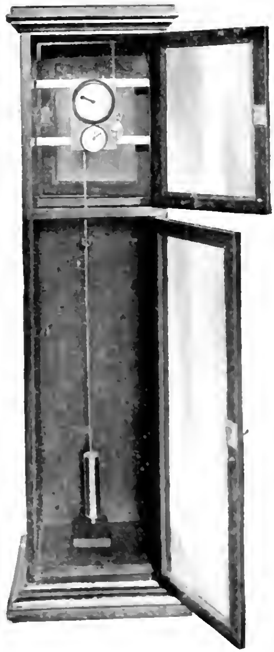


Fig. 1 The Warren Clock for Frequency Regulation

2. The new method practically eliminates the effect of all instrumental errors due either to calibration or temperature. The average frequency measured over periods exceeding 24 hours can easily be maintained within less than one hundredth of 1 per cent of its true value.

3. The scale of the instrument is so extended by the integrating process that close reading is wholly unnecessary.

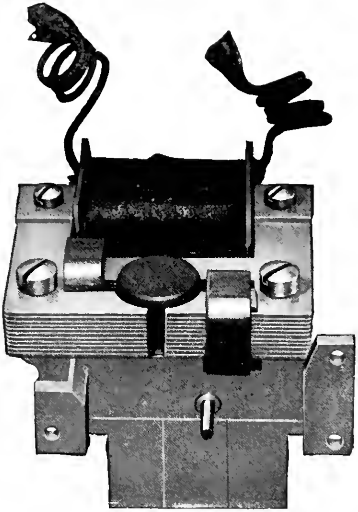


Fig. 2. Small Self-starting Synchronous Motor for Driving Synchronizing Hand (Full size)

Practical Results

Since October 1916, the frequency of the Boston Edison Company has been controlled by this improved method. The original Warren master clock has been running continuously 24 hours each day without repairs of any kind and without attention, except for daily comparison with Washington time signals and infrequent regulation. All the alternating current supplied from this station to 35 cities and towns and more than 50,000 customers has been controlled in this manner.

The improvement in frequency regulation may be seen by referring to Fig. 3, where the upper curve shows the average frequency for 24-hour periods during the month before the installation of the master clock, and the lower curve indicates the frequency thereafter. These curves are on the same large scale. The variations of the upper curve are probably due more to temperature changes than to any other cause, and it is likely that they would appear materially greater if measured through summer and winter. The lower curve, if continued to the present day, would probably show no variations large enough to be plotted on this scale.

It may be argued that the upper curve is acceptable commercially, but there can be no doubt that in the long run those manufacturers who use electric power, especially textile mills, gain materially by eliminating errors and variations in the average frequency, even as small as one half of 1 per cent. This must be so because the speed of all motors, and consequently the output of the mills, varies directly with the frequency. One half of 1 per cent would mean fifty dollars per day to a mill with a daily output of ten thousand dollars.

Fig. 3. Curve showing Improvement in Daily Average Frequency Secured by Installation of the Warren Master Clock

A New Field

The regulation of frequency by this method opens a wholly new field which bids fair to prove of considerable importance. The Warren motors, shown in Fig. 2, are very small and practically foolproof. They consume about two watts and will bring their load from rest up to absolutely synchronous speed within a second or two. One of these motors may be substituted for any clock mechanism with a certainty that it will run at the same rate as the master clock at the central station.

This means that any power company using the improved frequency control may eliminate all the troublesome clocks in graphic instruments, maximum demand meters, time switches, and similar devices by substituting the small Warren motors which take up much less room and are many times more powerful. A very considerable saving can be secured in this way, particularly with demand meters which are widely distributed. The cost of weekly winding disappears and the maintenance expense is greatly reduced. Much more accurate and reliable records are secured for two reasons: First, because the motor will keep far better time than any ordinary clock; Second, because the motor has so much power that it is not affected by greatly increased tension and friction upon the paper. It seems quite certain that for large systems the gain in re-equipping graphic instruments and demand meters will alone pay a generous return on the very moderate cost of adopting the new method. Motor-driven time switches for controlling multiple street lamps and many other purposes suggest very important possibilities for the future.

Standardized Frequency

In these days of consolidation and interconnection of large power plants and systems, uniform and correct frequency is especially desirable. Whenever two systems are to be tied together they must first establish the same frequency. It is much better that they should operate continuously, whether together or apart, at the same standardized frequency. This result can be accomplished with ease by the improved method of control.

Advantages Summarized

1. Average frequency of almost absolute accuracy.
2. Reduced physical and mental effort for operators.
3. More valuable service for customers.
4. Easier interconnection of systems.
5. Better service at reduced cost from graphic instruments, demand meters, and time switches.

Storing Direct-current Aluminum Arresters for the Winter

By F. T. Forster

Lightning Arrester Engineering Department, General Electric Company

This article points out the ill effects of leaving the plates of an aluminum arrester standing in the electrolyte when out of service in the winter months. A satisfactory method of preparing arresters for storage is given, and if these instructions are followed no trouble should be experienced when putting the arresters back in service.—Editor.

It has been the practice of some electric railways to store their direct-current aluminum lightning arresters in just the condition in which they are taken from the circuit, with the plates emerged in the electrolyte and oil. In other cases the cells are put in series and left connected to a 600-volt circuit with the evident belief that the small leakage current will keep the aluminum film in good condition during the time the arresters are out of service. Extensive experience shows that neither of these methods is satisfactory, and that unnecessary work and trouble is almost certain to result when the arresters are again put back in service.

In either of these ways of storing arresters, the results are much the same; the electrolyte slowly dissolves the film from the aluminum plates at ordinary room temperatures, more rapidly at higher temperatures, and after three or four months the film may have entirely disappeared. Sometimes the film will finally peel off the positive plate and will be found in the bottom of a jar as a grayish translucent skin. In the second method mentioned the potential of five volts per cell is too small to produce any film-forming effect.

When the film has been entirely dissolved as a result of standing in the electrolyte it is difficult to reform it without the facilities available at the factory. In order to build up a new film on an unformed aluminum electrode a considerable quantity of energy is required compared to that necessary to maintain the film, this forming operation resulting in heating if there is not sufficient radiating surface or other means of cooling, and this rise in temperature in turn retarding the formation of the film. Furthermore, the electrolyte is rapidly devitalized in the initial formation process, and there should be a relatively large quantity present. These facts mainly account for the difficulty in getting arresters back into service from which the films have been dissolved as a result of long standing.

Proper Method for Storing Arresters

When direct-current aluminum arresters are taken out of service the electrolyte should be poured into clean bottles and the aluminum plates washed in gasolene and then rinsed in clean warm water, after which they should be put back in the empty jar until again needed for service. With this simple method of storing arresters there will be no dissolving of the insulating film, and no trouble will be had in putting the arrester back in service. However, to make sure that nothing has happened to the plates of electrolyte during the storage period the arresters should be tested with a bank of lamps as described in the manufacturers' instructions furnished with each arrester. The electrolyte poured out of the cells will be mixed with oil, but if it is allowed to stand the oil will separate and the electrolyte can be syphoned off. Where a large number of cells are in use a good method is to pour the electrolyte into a large earthenware vessel provided with a draw-off in the bottom. When the oil is separated the electrolyte is drawn off into carboys or bottles and the oil into separate containers. It is just as important to provide clean bottles for the oil as for the electrolyte, for with the best separation that can be obtained by standing, the oil will contain some electrolyte which, should it become contaminated, will affect the remainder of the electrolyte on re-mixing and possibly shorten the life of the arrester. Although the use of new electrolyte is not urged, longer life of the arrester would no doubt result if new electrolyte were used when the cells are reassembled in the spring.

A series of tests covering a period of six months have been made in the laboratory of the General Electric Company to determine the relative values of these different methods of storing arresters. A number of cells filled with electrolyte were allowed to stand without voltage; others were allowed to stand with five volts applied; and still others had the electrolyte poured out and the plates washed and rinsed in clean warm water. At the end of the six months' period the cells were put back in operation with the following results:

Description of Cells	Time in Series with Lamps	Temperature Before	Temperature After	Amperes Start	Amperes Finish
Plates in electrolyte (5 volts applied)	30 min.	22 deg. C.	31 deg. C.	1.20	0.30
Plates in electrolyte (no voltage applied)	30 min.	22 deg. C.	34 deg. C.	1.50	0.305
No electrolyte	5 min.	22 deg. C.	22 deg. C.	0.20	0.02

The first two lots had to be given special attention and run for an additional five hours before the current dropped to $2\frac{1}{2}$ to 3 milliamperes, a value low enough to insure good operation without heating. The third quite quickly formed up without overheating or requiring special attention. These tests prove beyond doubt the ill effects of allowing the formed electrodes to stand in electrolyte.

In connection with applying a reduced voltage to the arresters while in storage the following explanation of aluminum cell phenomena may be of interest.

The aluminum film has the property of acquiring a critical voltage value corresponding to any voltage that is applied to it for a considerable length of time, provided this voltage is below the maximum critical value. For example, if the maximum critical value of a film is 420 volts direct current, and 250 volts is applied for a long enough time, then the film will assume a critical value of 250 volts; or in other words, dissolution of the film will take place until a thickness of film is reached that will be maintained at 250 volts. When the film has settled down to this value, then any increase of voltage will be accompanied by a rush of current. If the increased voltage is still below the maximum critical value, 300 volts for instance, and is sustained, then the current will form the film to a new critical value and the current will gradually fall to a low value as the film strength approaches the new critical value.

If a number of arrester cells are put in series on high voltage so that there are only 5 or 10 volts across each cell, it will be readily understood from what has just been said, that after long standing there would only be a 5- or 10-volt film in place of a 300-volt film, or there would be practically no film. This has been amply proved by tests. No advantage is therefore gained by this method of storing arresters when out of service.

The only safe method of storing direct current arresters is to remove the electrolyte, clean the electrodes, and let them stand in the empty jars until needed again.

IN MEMORIAM

GEORGE LEWIS EMMONS

George Lewis Emmons, eldest son of George E. and Helen G. Emmons, died at his late residence, 401 Rugby Road, Schenectady, N. Y., on Saturday, October 5th, at 1.30 p.m., after a short illness of influenza.

Mr. Emmons was 32 years old, and was born in Lynn, Mass., December 18, 1886. He graduated from Yale University with the class of 1908, and after graduation entered the employ of the General Electric Company at Schenectady, where at the time of his death he held the position of Supervisor of Order and Stock Department.

Mr. Emmons was an able executive and possessed marked talent for organization. His genial disposition and democratic manner won for him many friends, especially among his business associates. He was widely known throughout the Schenectady Works organization, and enjoyed the esteem of all ranks of employees.

Mr. Emmons is survived by his wife, Kathryn George, his parents, and a younger brother, Lawrence, who is now living in Passadena, California.

LIBERTY LOAN SUBSCRIPTIONS BY GENERAL ELECTRIC EMPLOYEES

	FIRST LOAN		SECOND LOAN		THIRD LOAN		FOURTH LOAN		ALL LOANS
	No. Subs.	Amount	No. Subs.	Amount	No. Subs.	Amount	No. Subs.	Amount	Amount
Schenectady Works, inc. General Offices............	13,309	$1,057,400	20,905	$1,497,600	21,869	$1,646,600	23,205	$2,563,200	$6,764,800
Philadelphia Works					240	14,550	318	29,100	43,650
Lynn Works......	8,737	559,800	9,111	555,000	8,819	561,400	9,603	811,500	2,487,700
Pittsfield Works...	4,145	287,400	4,413	289,050	4,978	326,200	5,802	433,100	1,335,750
Erie Works.......	2,384	177,450	2,360	160,050	4,468	355,450	5,893	628,150	1,321,100
Fort Wayne Works	2,129	152,050	2,922	196,600	3,413	245,750	3,538	277,250	871,650
Edison Lamp Works	3,212	213,650	3,387	200,250	*1,293	*86,860	5,039	310,600	811,300
Sprague Elec. Works	802	57,850	594	56,450	1,482	116,850	2,046	215,900	447,050
Nat'l Lamp Works.	3,389	278,200	2,908	250,400	6,079	437,100	7,270	770,000	1,735,700
District Offices....	1,748	219,050	1,717	224,100	2,610	329,250	2,702	494,450	1,266,850
Foreign Selling Companies......				18,000		7,000		10,900	35,900
Total.........	39,855	$3,002,850	48,340	$3,447,500	55,251	$4,126,950	65,416	$6,544,150	$17,121,450
Average individual subscription.....	$75		$71.50		$75		$100		
In Percentage of First Loan:									
No. Subscribers	100%		121%		138%		164%		
Total Amount.	100%		116%		138%		217%		
Percentage of Subscribers to Total Employees......	57%		67%		76%		90%		

* Subscriptions not solicited from employees receiving less than $1,000 per annum on account of previous War Savings Stamp Campaign.

ELECTRIC WELDING

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DECEMBER 1918

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WITH SPECIAL REFERENCE TO

SHIPBUILDING

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Director General, Emergency Fleet Corporation

GENERAL ELECTRIC REVIEW

ELECTRIC WELDING AND OUR SHIPBUILDING PROGRAM

By David B. Rushmore

Engineer, Power and Mining Engineering Department, General Electric Company

For reasons of self interest, of class segregation, of heredity, of education, of health, etc., all individuals are sharply divided into two classes, usually known as liberals and conservatives. In times of national stress it is the liberal-minded, progressive individual who, of necessity, takes the lead, and the function of conservatism becomes of less importance.

Industry in war time becomes founded on an entirely new basis. Production and speed of manufacture become of first importance, and cost becomes, to some extent, secondary. New methods must be introduced with a rapidity unknown in peace times, and the taking of some chances becomes an absolute necessity The desirability of avoiding machine work, the desirability of reducing to a minimum the labor item, the necessity for utilizing unskilled labor wherever possible, all become of great importance. The necessity for long life is not always present. Substitutes must be found for many materials where shortages exist, and margins and factors of safety must be reconsidered and, wherever possible, reduced.

The steel industry with its allied and auxiliary developments naturally becomes of first importance. The uses of iron and steel in war time as well as in times of peace are so manifold as to preclude a detailed listing. In practically all the uses of steel several parts must be joined together to form the whole, and in very many of these operations rivets have been the means of union employed. In the building of ships, in the fabrication of all structural material wherever steel plate is used, and in places almost without number the rivet has been the means of union between two separate steel parts. In accordance with the law of economics, wherever a process can be performed in such a way as to show an advantage in quality, speed, cost, or quantity, it must surplant other methods. Electric welding in some of its various forms gives every promise of replacing riveting in the enormous field which the latter has long held for its own. It is only when a rival appears upon the field that the characteristics and claims of a process are properly investigated. The rivet has occupied a position of respect and acceptance which a more careful scrutiny shows, from an economic standpoint at least, has not been without its many questionable virtues.

Electric welding *per se* is not a new art, but in its various forms has been used for many years. Always art precedes science. The practical application of electric welding has been over a varied field, but even now its utilization is confined to a very small percentage of its possible applications. To those who have studied the subject, the possibilities of arc, spot, butt, and other forms of welding are well known. The results which can be obtained are matters of experience, and years of actual service have been sufficient to demonstrate the unquestioned reliability of these processes.

The elaborate and careful scientific investigation now under way to determine the characteristics and limitations of all forms of electric welding will soon place knowledge of the art on a broad basis comparable to that of our best engineering methods, and far in advance of the knowledge of riveting which electric welding gives every promise of soon displacing.

The repair of the willfully damaged German ships has been one of the most spectacular demonstrations of the possibilities of the welding art, but to those familiar with the subject this work contained no element of surprise. The enormous shipping program of the present and of the future offers opportunity for the use of electric welding in which the economic advantages are unquestioned and in which the quality of production has already been fully demonstrated. In the manufacture of munitions, of arms, and in those industries in which steel and iron parts are employed, there is practically no limit to the opportunities for employing electric welding. In salvage and repair work it is being rapidly introduced; in original manufacture it is coming more slowly but surely.

A number of organized groups of men with creative minds and progressive tendencies are at present engaged in developing the art and in extending its application. That electric welding will, in the immediate future, play a large part in the industrial fabrication of iron and steel is unquestionable.

* * *

With the ending of the war the need for the enormous quantities of munitions, airplanes, trucks, and the vast stores of supplies that are necessary to feed and equip an army on a war basis—to produce which the main industrial effort of the country was concentrated—abruptly ceased, and arrangements for curtailment of production in some lines and cancellation of entire orders in others were immediately made.

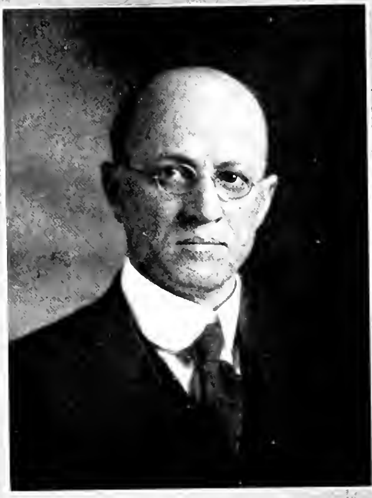
Ships, ships, and more ships was an urgent and familiar war cry; yet the coming of peace does not release us from the necessity of building ships—the need for bottoms is just as urgent now, if not so vital. Food in larger quantities than ever must be sent to Europe, not only for our army and the peoples of the nations allied with us, but also for our late enemies, who are near starvation.

Then, too, there is the task of returning our soldiers, two millions or more of them, while the huge demands on cargo space for reconstruction will soon begin to be felt. English shipping is assisting to a large extent to make up the deficiency of American craft; but Great Britain will by degrees withdraw her tonnage to re-establish her old trade lines with Canada, India, Argentine, Africa, etc. The floating supply of ships is everywhere inadequate, and we cannot escape the truth that the German submarines put a big crimp in the world's shipping. According to a recent statement issued by the United States Shipping Board the losses in mercantile shipping to September 1, 1918, were 21,404,913 tons dead weight, while construction during the same time was 14,247,825 tons and seized enemy tonnage to the end of 1917 was 3,795,000; the net loss thus being 3,362,088 tons.

Thus we see that there is a large void to be filled before we are back to the basis existing prior to August 1914. American yards are launching ships at an amazing rate, the deliveries for September being 369,330 tons against 231,635 for Great Britain; but if we are to realize our ambitions for world-wide trade, with promises of a development unparalleled in history, we cannot relax on our shipbuilding program. Indeed, it would be sheer folly to abandon a policy that has cost so much and offers so rich a reward.

The race between submarine sinking and construction focused attention on every means that gave promise of expediting the output of the shipyards. Thus the idea of the fabricated ship was evolved, by which ships could be built much as are automobiles. There yet remained the slow and laborious process of riveting, which more than any one thing retarded construction. Attention was turned to electric welding as a substitute method. A committee was appointed to investigate the possibilities of the process and under its direction an immense amount of research has been done. The conclusions arrived at are that there are no outstanding technical questions requiring solution in order to proceed at once to the construction of welded ships. Thus, in the course of a few years we may hope to see the electrically welded ship the rule instead of the exception.

A brilliant future for electric welding is plainly disclosed by the contributors to this issue of the General Electric Review.



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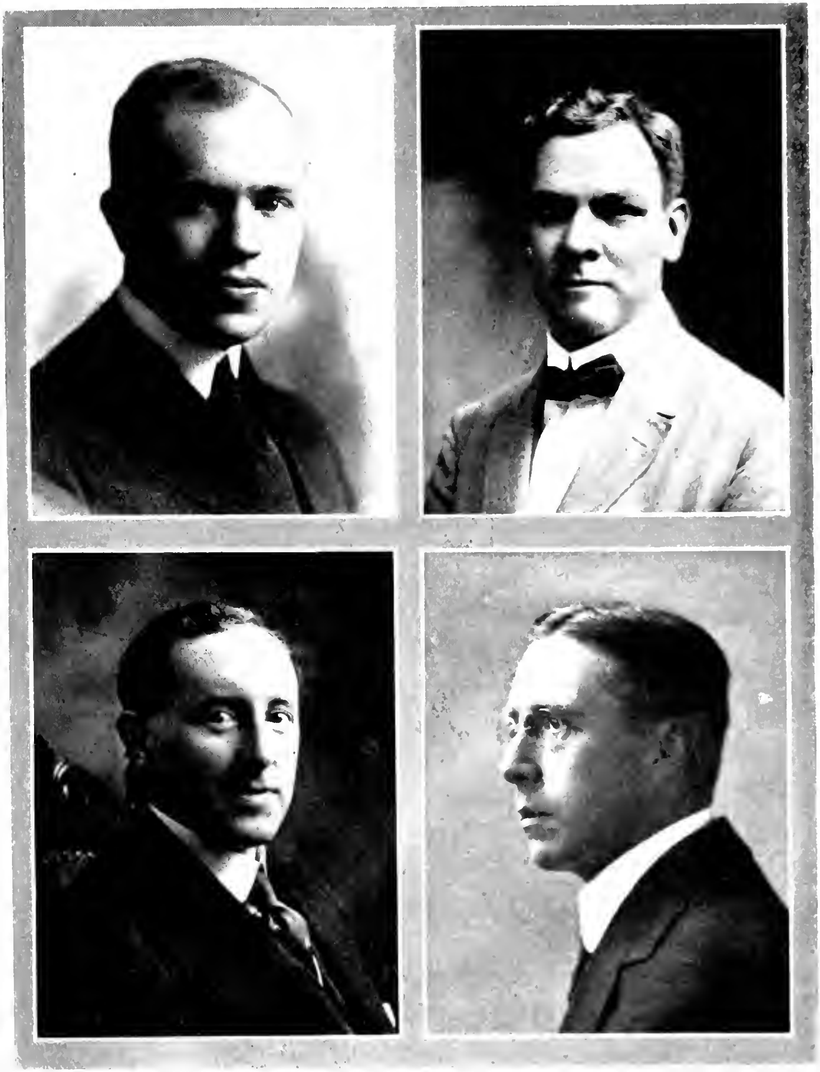

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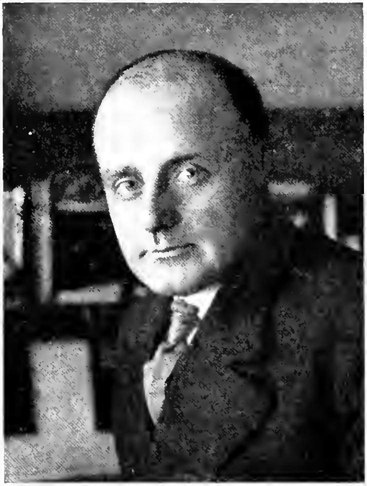

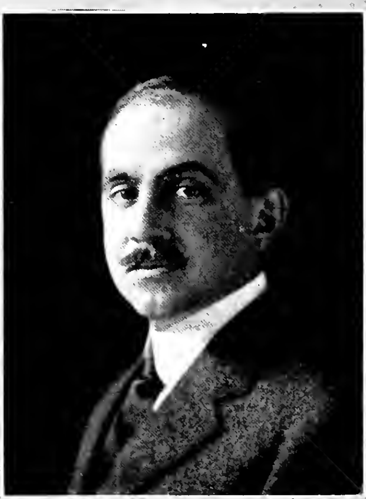

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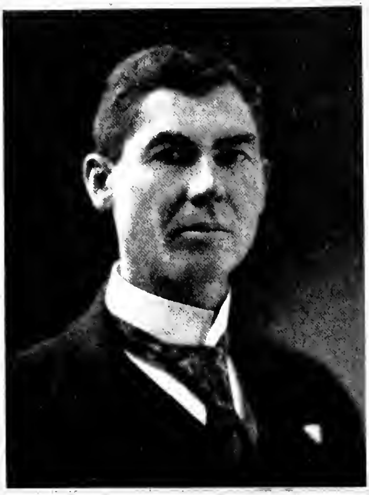

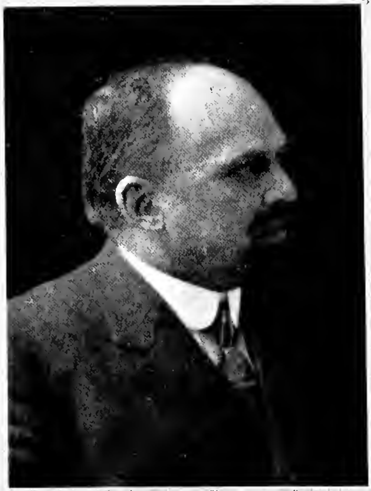

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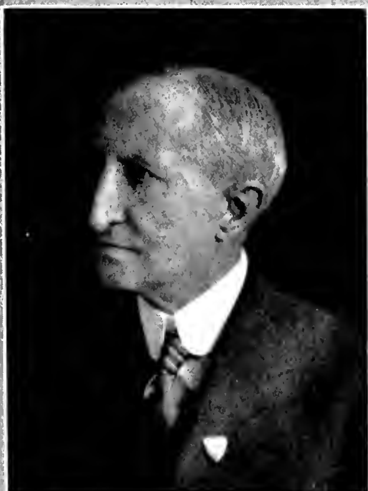

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Electric Welding in Shipbuilding

By Comfort A. Adams

Chairman, Welding Committee of the U. S. Shipping Board, Emergency Fleet Corporation; President, American Institute Electrical Engineers

In this article, Professor Adams enumerates all of the factors of importance that bear on the subject of electric welding, and briefly discusses each. Among these factors are the question of when to use arc or spot welding, electrodes for arc welding, training of arc welders, the use of direct or alternating current, size of electrodes and strength of current, automatic arc welding machines, strength of welds, relative cost of welding over riveting, etc.—Editor.

Introduction

The work of the Welding Committee of the Emergency Fleet Corporation was started about fifteen months ago under the auspices of the Standards Committee of the A.I.E.E., transferred about a year ago to the General Engineering Committee of the Council of National Defense and finally (in February 1918) taken over by the Emergency Fleet Corporation.

This work is one of the most striking instances of co-operation of competing interests and particularly of co-operative industrial research.

The present Committee consists of more than 110 members representing practically all of the interests concerned with the application of electric welding to shipbuilding. The personnel is given below and includes some of the foremost representatives of each group.

THE WELDING COMMITTEE OF THE UNITED STATES SHIPPING BOARD EMERGENCY FLEET CORPORATION

Comfort A. Adams, Chairman, President American Institute of Electrical Engineers; Professor of Electrical Engineering, Harvard University and Massachusetts Institute of Technology.
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Maurice Lachman, Universal Electric Welding Co., New York.
R. P. Jackson, Westinghouse Electric & Mfg. Co., East Pittsburgh.
W. H. Patterson, Westinghouse Elec. & Mfg. Co., East Pittsburgh.
D. H. Wilson, Wilson Welders & Metals Co., New York.
R. S. Drummond, Wilson Welders & Metals Co., New York.
W. S. Cozad, Wilson Welders & Metals Co., New York.
W. A. Turbayne, U. S. Light & Heat Corporation, Niagara Falls.
M. W. Randall, Air Reduction Sales Co., New York.
E. L. Mills, Air Reduction Sales Co., New York.
R. T. Peabody, Air Reduction Sales Co., New York.
M. H. Roberts, Air Reduction Sales Co., New York.
Alexander Jenkins, Alexander Milburn Co., Baltimore.
M. M. Smith, Commercial Acetylene Co., New York.
Augustine Davis, Davis-Bournonville Co., Jersey City.
Stuart Plumley, Davis-Bournonville Co., Jersey City.
F. A. Rogers, Davis-Bournonville Co., Jersey City.
H. R. Swartley, Davis-Bournonville Co., Jersey City.
W. M. Beard, Linde Air Products Co., New York.
L. H. Davis, Linde Air Products Co., New York.
F. A. Wilson-Lawrenson, Linde Air Products Co., New York.
C. C. Phelps, Oxweld Acetylene Company, Newark.
H. W. Jacobs, Oxweld Railroad Service Co., New York.
H. S. Smith, Prest-O-Lite Company, New York.
P. F. Willis, Henderson-Willis Mfg. Co., St. Louis.
J. H. Deppeler, Metal & Thermit Corporation.
G. L. Brunner, Brunner Mfg. Co.

Other Members

Charles Wirt, Wirt Co., Germantown, Pa.
C. P. M. Jack, Naval Architect, New York.
E. Wanamaker, Chicago, Rock Island & Pacific Railway Co., Chicago.
S. W. Miller, Rochester Welding Works, Rochester.
W. E. Symons, Galena Signal Oil Co., New York
Thomas Shipley, York Manufacturing Co., York, Pa.
C. B. Coates, Chicago Pneumatic Tool Co., Chicago.
J. A. Osborn, American Car & Foundry Co., St. Louis.
William Siebenmorgen, Consulting Engineer, New York.
Fred Allison, Ford Motor Co., Detroit.
T. J. Litle, Lincoln Motor Co., Detroit.
D. G. Stanbrough, Packard Motor Car Co., Detroit.
D. L. Galleys, Nordyke & Marmon, Indianapolis, Ind.
F. N. Speller, Metallurgical Engineer, National Tube Co.
J. I. Banash, Underwriters Laboratories, Chicago.
Victor Mauck, John Wood Mfg. Co., Conshohocken, Pa.
P. A. E. Armstrong, Ludlam Steel Co., Watervliet, N. Y.
J. R. McAllister, New York Central R. R., West Albany, N. Y.
Zey Jeffries, Director of Research Aluminum Castings Co.
E. H. Peirce, American Steel & Wire Co.

Although electric welding has long been in common use in many industries, its application to shipbuilding has been thus far largely confined to repair work and to the welding of minor parts where failure would not be fatal to the safety of the ship; and although many of those most familiar with the art and what has already been accomplished have been confident from the beginning that electric welding could be safely applied to the main structure of a ship, so much poor work has been done that the Classification Societies, without whose rating insurance cannot be obtained, have been slow to approve of the application of electric welding to the capital parts of a ship.

Moreover, there are still many problems to be solved before the art is on a sound scientific basis as well as on the most efficient commercial basis. The following facts will make this clear:

Arc vs. Spot Welding. Where shall each be used? Arc welding is relatively slow, requiring more labor but a lighter, more portable apparatus, and can be carried out in locations where spot welding is impossible. Spot welding requires a very heavy, bulky, and expensive apparatus and more power, but is much more rapid and saves more labor. It looks now as if spot welding would find a large field in shop fabrication work whether for shipbuilding or for other structural steel work, and it ought, in portable form, to prove a great labor saver in the assembly and tacking of the plates and frames of a ship.

Spot welding requires less skill on the part of the operator and lends itself more readily to effective inspection.

Electrodes for Arc Welding. These now range in cost from 8 to 12 cents per pound for bare electrodes, and from 20 to 75 cents per pound for flux-covered electrodes.

There is also a wide range of chemical composition from almost pure iron to steel with high manganese, fairly high carbon, and in some cases with copper.

The striking fact in this connection is that as far as tensile strength is concerned good results have been obtained with nearly all of these extreme varieties—even with common fence wire and wire nails.

Training of Arc Welders. There is a wide difference of opinion on this point, but it is now certain that where the strength and ductility of a weld are important, thoroughly skilled operators are necessary, and that such cannot ordinarily be produced with less than 6 to 8 weeks training.

Arc Welding Apparatus. These vary enormously in price, weight, space, and efficiency, and it is only through a vigorous campaign of education on the part of the Welding Committee that sufficient information has been made generally available to enable a prospective user to select his apparatus intelligently.

Good welds and bad welds can be made with almost any of the types of apparatus now on the market, although it is easier with some than with others. In brief, the characteristics of the apparatus are nothing like as important, within the existing range, as the skill of the operator.

Direct Current or Alternating Current. There are vigorous advocates of each, and each has its merits; but there are many factors that determine the wise choice in any given case.

Electric Distribution of Power and Location of Machine. This is another problem of importance in shipyard work to which little attention has as yet been given, and which should be considered in connection with the type of welding apparatus employed.

Size of Electrode and Current Adjustment. The current adjustment for different sizes and types of electrode, and the size of electrode and current strength for different plate thicknesses, are still matters of opinion and usually left to the operator, although tables are provided by several manufacturers of welding apparatus.

Type of Joints for Ship Plates. The type and detailed proportions of joints have a large influence on the amount of welding material and labor involved, and in some degree upon the strength and ease of welding. Some progress has been made in solving this problem, but much still remains to be done. The final results will obviously influence the design of the welded ship of the future.

Carbon Arc vs. Metallic Arc Welding. While it has been generally assumed of late that carbon arc welding is suitable only for rough work, such as filling blowholes in castings, etc., where quantity is more important than quality, some information now at hand seems to indicate that such a conclusion is premature.

Automatic Arc Welding Machines. Several of these machines are now being developed and some of them are very promising, not only because of greater speed, but also because of greater uniformity of work and the elimination of the human element, at least to a considerable extent. There are doubtless corners where such a machine cannot work, but if it is successful for the straightaway parts of ship joints it will constitute a great step towards the economy of this application.

Methods of Assembly of Ship Plates and Shapes. With the introduction of electric welding in shipbuilding comes the necessity of devising new methods of assembly and holding the plates in position for welding. Several methods have been proposed, but their success can be demonstrated only by actual experience.

Cooling Stresses. Coupled with the order of plate assembly is the order and manner of making welds to avoid locking up cooling stresses in the structure of a ship. Sufficient experience has already been had with fairly large structures to avoid serious danger in this connection, although this work is still progressing.

This hurried review will give a rough idea of the work still to be done before the welded ship reaches a state of reasonable perfection and economy of production, but it will be well also to outline certain established facts upon which the Welding Committee bases its confidence in the immediate commercial superiority of the welded ship over the riveted ship.

Strength of Welds. Spot-welded joints can readily be made stronger than the plates joined. Arc-welded butt joints can be dependably made with an average strength of over 90 per cent of plate strength, and when backed up by butt straps with an average strength of over 100 per cent, whereas triple-riveted joints have a strength of 70 per cent or less.

Ductility and Fatigue. Owing to the relative brittleness of arc-welded joints, much fear has been expressed as to their ability to withstand long-continued vibration stresses and shocks. Exhaustive tests by Lloyds' Register of Shipping in England have proved the possibility of making welds which will withstand such stresses at least as well as riveted joints even when the welds are not reinforced. Moreover, the larger factor of safety of the actual welds as made on the ship applies to this type of stress as well as to simple tension or compression.

Relative Cost. On the minor parts of a ship, welding involves a saving of at least 60 per cent over riveting, and on the hull plating, etc., a saving of about 25 per cent, as a conservative estimate. With automatic welders and improved methods of assembly this latter figure will surely be raised. This applies to the whole steel structure of the ship but not to the equipment and interior finish.

Saving of Material. As more confidence in the value of the welded joint is demonstrated by actual experience at sea, the strength members of the welded ship can be reduced because of the higher efficiency of the welded joints as compared with the riveted joints. This will mean a saving of at least 20 per cent in the steel required. Even at first there will be a slight saving in rivets, angles, and overlaps of about 5 per cent.

Watertightness. With arc-welded seams no caulking will be necessary and watertight joints will be so in fact as well as in name, and will remain so.

In every naval battle of the great war the British battleships and destroyers have returned with their tanks (double bottoms where fuel oil is carried) leaking so badly that they had to have most of the joints arc-welded. This will not be necessary with the welded ship.

Attitude of the Classification Societies. While the Classification Societies in this country have formally approved for welding only certain minor parts of a ship, British Lloyds after exhaustive experiments have issued regulations and specifications under which they will classify a welded ship. Several of small size are already under construction in England, in addition to the 275-ton cross-Channel barge in service since June last.

On this side a 42-ft. welded boat has been in service winter and summer for three years, and has undergone the severest tests of service with a record unequalled by any riveted boat.*

A 42-ft. welded section of a 9600-ton ship is being built at Kearny, N. J., and there is good prospect that a 5000-ton cargo ship larger than any planned in England will be authorized shortly.

Thus, making all reasonable allowances for difficulties to be encountered, it would seem not over optimistic to say that the welded ship is the ship of the future and of the not distant future, although it is obvious that it will take years to transform existing shipyards to build welded ships.

* See page 844.

The Adequacy of Welding in Constructing Hulls of Ships

By H. M. Hobart

Chairman, Welding Research Sub-committee of the Welding Committee of the U. S. Shipping Board; Consulting Engineer, General Electric Company

Although electric arc welding has been employed for years in many industries, very little of practical value has been written about the process and almost no data were available from which deductions could be drawn to determine the suitability of the process for specific applications. It remained for the exigencies of the war to bring about the pooling of all available information and the collaboration of competing interests to advance the art. The progress has been largely accelerated by the Welding Committee of the Emergency Fleet Corporation; and it has been the duty of the Research Sub-committee of the Welding Committee to determine the relative merits of the many different systems and equipments. The present attitude of the Welding Research Committee is that, although carefully planned research work will undoubtedly lead to further improvements, there are no outstanding technical questions requiring solution in order to proceed at once with the construction of welded ships.—Editor.

In the autumn of 1917, the author, while in England, had the privilege of investigating at first hand the welding work which was then in progress under the direction of the British Admiralty and Lloyd's Register of Shipping. At that time, not only were many interesting tests being made at Portsmouth Dockyard, at the Cammell-Laird Shipyard at Birkenhead, and elsewhere, but also the plans had been perfected and the material delivered for the construction of the cross-Channel barge which has since been completed and launched and has been in service for several months, transporting material between England and France.

Under the stress of war conditions, it was expedient to employ that method which required the least machinery and which could be applied with the least delay. In view of these circumstances the wide and practically exclusive adoption of any particular method does not constitute proof of its superiority to other methods. Nor, on the other hand, does it exclude the possibility of its being the superior method. The fact of its approval by Lloyd's Register and the Admiralty, after exhaustive tests, does, however, constitute very satisfactory evidence of its being quite sound and adequate.

The method consisted in arc welding with a flux-covered electrode of a specific composition and construction. The work could be done from any 120-volt supply of either alternating-current or direct-current electricity, and when such a supply was available, all the electrical apparatus required was a rheostat, an ammeter, a voltmeter, and a circuit breaker.

A distribution pressure so low as 120 volts is, however, rare in England, that country having in the early days of the industry standardized a pressure of some 220 to 240 volts for incandescent lighting, so that almost all distribution circuits (aside from railway services) are for 240 or 480 volts. Hence it will be customary to interpose a transformer when the supply is alternating current, or a motor-generator for direct current.

While generous credit is due to the exploiters of the particular system at present employed, since they have shown splendid enterprise and thoroughness, and have given evidence, by undertaking extensive research work, of their appreciation of their responsibilities, it is of interest to call attention to the desire of Lloyd's Register to have the opportunity to investigate other welding systems with a view to their ultimate approval when they are found adequate for use in ship construction. This attitude is evidenced in the following notice which appeared in the London *Times* for September 13, 1918:

"**Electric Welding for Shipbuilding**

"The Secretary of Lloyd's Register of Shipping writes, with regard to the use of electric welding for ship construction, that the Committee of Lloyd's Register, who have already approved of one system of electric welding, are prepared to consider applications from any electric welding companies to have their processes recognized by the Society, and to have their names inserted in a list of companies whose processes have been approved of, as fulfilling the Society's conditions."

These British accomplishments looked so good that the author felt confident that facts relative thereto would be of interest here in America and he brought back quite a lot of information. In general, it may be said that this material was cordially received and was given careful study. In several quarters, however, far from being welcomed, the mere mention of the nature of this information brought forth statements to the effect that America had long known all about flux-covered electrodes; that no advantage attended their use; that alternating current couldn't be used for arc welding; and that more arc welding experience had years ago been gained on American railways than Britain had ever even heard about. The author cheerfully agrees that there is a great deal in this last claim that America has made very fine progress in the application of arc welding in the case of several of its large railroad systems. The progress in America in applying arc welding in this and other fields received high praise from Major James Caldwell, R.E., of the Welding and Labour Saving Division of the British Admiralty Labour Department, who has recently (at the invitation of the Emergency Fleet Corporation) spent some three months in America in connection with the subject of the application of arc welding to ship construction.

In a large measure owing to the efforts of the Welding Committee of the Emergency Fleet Corporation, under the Chairmanship of Professor C. A. Adams, events have moved rapidly during the last few months. The Welding Research Sub-committee was established by Professor Adams in April. While, as already stated, arc welding had been employed for years in many industries with very gratifying success, there had been but little concerted action among the exploiters of competing systems, or interchange of ideas or experiences, and individual opinions were greatly at variance. By the end of the first few months of its existence it has become apparent to the Welding Research Sub-committee that the limitations within which welding can be done, which will be in all respects satisfactory, are very wide and that the choice of electrodes, systems, and other conditions are to a considerable extent governed by economics, and also by the time required to provide the necessary machinery and materials.

The limitations of this article will permit of dealing only briefly with a single group of the very many interesting questions which are being examined by the Welding Research Sub-committee. It must be repeated that it is rarely a question of a good result, but usually it is a question of which of two or more conditions yield *the best* result, or yield a given result at the least cost, or in the briefest time, or with the least demand for labor.

One of the most interesting matters relates to the relative merits and characteristics of direct-current and alternating-current arc welding. But little over a year ago, practically all arc welding was done with direct current. It had, indeed, become a universally accepted tradition that alternating current was unsuitable. Today we find a great deal of arc welding done with alternating current. Nevertheless, the more usually held view is to the effect that direct current is the more suitable. The data at hand are very conflicting. It has been contended that alternating-current welding is slower. One observer reports as follows:

"With the most expert operator (who, by the way, learned his business on the alternating-current arc), welding in this particular case only for a short period on each machine, on which he tried to do his absolute best in both cases, his speed was more than 25 per cent greater on the direct current than on the alternating current. A less expert operator showed a speed of less than two thirds on the alternating current than he showed on the direct current. An operator who had been handling the arc only for about two months, and in all cases handling direct current during that time, was unable to do any welding at all with the alternating-current arc. This comparison was made in one of the large shipyards and, I believe, showed the alternating-current arc to the very best possible advantage."

A second observer states that:

"We have found that welds can be made with alternating current as well as direct current, the only difference being that it is slightly more difficult to hold the alternating-current arc. This may be readily overcome after a little practice."

From this second observer has recently been received the report of a test on a certain kind of electrode. He states:

"Its operation on 140 amperes, 115 volts, alternating current is very good. It also works satisfactorily on 130 amperes, 75 volts, direct current, but the metal flows *more slowly* on direct current than alternating current."

This second observer is an engineer with wide knowledge of arc welding and some weeks after making the above report he stated to the author that his careful observations go to show that alternating-current arc welding is inherently faster than direct-current arc welding.

In the matter mentioned in an earlier paragraph of this article, namely, the greater difficulty of maintaining an alternating-current arc (involving the necessity of acquiring the skill to hold a very short arc), it has been contended that an alternating-current weld will actually be of superior quality, since there is not so good opportunity for access of oxygen or nitrogen to the weld with a shorter arc. A third observer reports as follows:

"Tests made have demonstrated conclusively that it is possible to do as good, or perhaps better, welding with alternating current as with direct current. No very decided difference has been noticed between welds made with alternating current and those made with direct current, but the welder who did most of the alternating-current welding says that in his opinion the alternating-current welds are better than the direct-current welds. This same opinion has been expressed by the machinist who made repairs on a small tank welded with alternating current. He said that the weld metal was better, more dense, and had fewer blowholes than a direct-current weld."

But the first observer quoted in this matter of direct-current versus alternating-current welding, states:

"As regards the strength of the weld, there is not the slightest doubt that a greater strength can be gotten in a test piece if that is all the work the man is going to do for some time. The facts, however, are that as the man's hand becomes fatigued in holding the alternating-current arc his consequent breaking of the arc becomes more frequent, which means less strength in the weld because every time the arc is broken a bad spot is left in the weld."

The Welding Research Sub-committee's own tests of alternating-current welds as compared with direct-current welds are not yet completed, but from the few at hand, which were made on ½-in. thick ship plates, there is nothing to choose between alternating-current and direct-current welds as regards bending toughness and tensile strength.

The view is presented with considerable persistency that the low power-factor associated with alternating-current welding will lead to costs offsetting any advantages. To this the alternating current advocates reply that since for ship welding on an extensive scale motor-generators will be required, this power-factor handicap will only affect the generator and its circuit and will not affect conditions as regards the motor or the circuit from which it is supplied.

Nor does this exhaust the alternating current versus direct current controversy. There is, at present, no agreement as to the influence of the periodicity on the character of the weld nor whether alternating-current welding will be more satisfactory or more rapid with flux-covered than with bare electrodes.

In a contribution to the discussion of Major Caldwell's paper entitled, "Notes on Welding Systems" read before the Institution of Engineers and Shipbuilders in Scotland on January 22d, Mr. E. H. Jones, with reference to the matter of the use of alternating current for arc welding, spoke as follows:

"I would like to take this opportunity of drawing attention to the undoubted merits of alternating current for arc welding. For some reason which I was unable to fathom, the general impression was that continuous current was superior to alternating for arc welding, but, as a matter of fact, I found that alternating current was far superior to continuous, and I would recommend the use of alternating current on every possible occasion. Apart entirely from the capital outlay needed, which was vastly higher in the case of continuous current the control of the current was much easier to effect. I estimate that the amount of current which would be necessary to feed 20 operators with continuous current would suffice to feed 28 with alternating current."

In view of the mass of conflicting information and opinion concerning many aspects of arc welding (of which the single instance above cited of alternating current vs. direct current is typical), it was natural that for the first couple of months or so there should have been some in the Committee who experienced a certain degree of concern with regard to the extent to which the welding arc was ready for application on a wide scale for shipbuilding.

For the hull of a welded merchant ship, the welding relates exclusively to mild steel plates and forms. Some of the confusing impressions arose from a failure to distinguish between such work (which, relatively, is very simple) and the much more complicated problems associated with the welding of cast iron, high-carbon steel, and various non-ferrous metals.

The Committee, however, set itself earnestly to the task of sifting this evidence and obtaining, at first hand, information on the various points of importance. Gradually a reasonable perspective of the actual state of affairs was acquired, as regards reliable arc welding of the kind required in shipbuilding in the hands of experienced people. In other words, the Committee learned to distinguish between the extensive and highly satisfactory commercial accomplishments on a wide scale, of which it found any amount, and the work of the novice and amateur.

The present attitude of the Welding Research Sub-committee is to the effect that, although (as in any art) carefully planned research work will lead to further improvements, *there are no outstanding technical questions requiring solution in order to proceed at once to the construction of welded ships.*

It would exceed the space limitations set for this article to give even a bare list of the work which the Welding Research Sub-committee has carried out and has in hand. The investigations are distributed among several Special Committees to deal with specific branches of the subject, since the work bristles with questions in metallurgy, chemistry, heat, electricity, light, spectroscopy, strength of materials and structures, and psychology.

The Welding Research Sub-committee, besides being a Sub-committee of the Welding Committee, is also a Sub-committee of both the Metallurgical and Electrical Engineering Sections of the Engineering Division of the National Research Council.

A superficial consideration might lead to the conclusion that electric welding is unique with respect to the bewildering variety of problems and alternative methods and opinions associated with it. But those who have been closely concerned through several decades with the development from their early beginnings, of such arts as, for example, electric traction, or electric illumination, will find many very close parallels. Indeed there come to us, as in visions from the past, the memory of hundreds of debates on alternating current versus direct current; single-phase versus polyphase; three-phase versus quarter-phase; 125 versus 60 versus 50 versus 40 versus 25 versus 15 cycles; rheostatic versus series-parallel control; double-reduction versus single-reduction versus direct drive; overhead versus third-rail versus conduit; wheel versus bow collectors; roller versus sliding collectors; and literally hundreds of other questions on which, at one time or another, vast sums of money have been spent in arriving at a decision, and thousands of pages of technical papers have been discussed before engineering societies.

There would appear, however, to be one characteristic distinction between the welding situation and these historical instances. This distinction relates to an innovation which, while *accelerated* by the war emergency, is a product of an enlightened policy, which is rapidly growing in favor. It consists in the pooling of experiences and opinions heartily and unreservedly. The custom has been developing for some time, notably in connection with the work of Standards Committees of various Engineering Societies, not only in America but in other lands and very especially in Britain. It is being demonstrated that there is ample opportunity to have full advantage of the spurs of competition and emulation (indeed to *accentuate* their force) by this plan of bringing independent interests into touch with one another under such conditions as involve interchanges of experiences to an extent which formerly would have been deemed utterly inexpedient. It is yet to be demonstrated whether this plan permits of so clearly co-ordinating in people's minds the great number of questions involved as to permit of dealing effectively with each question. In the more elementary and (probably) more wasteful evolutionary methods employed in the instance of electric railways and electric illumination, the couple of hundred or more alternatives came prominently to people's minds at the rate of only a dozen, or thereabouts, per year for some twenty to thirty years. In the present instance of the rapid extension of welding, we are endeavoring to deal *in parallel* with the comparison of a very large number of alternative methods, and to arrive, in a few months, at definite decisions regarding the relative characteristics and merits of very many alternatives, the majority of which have already, in a general way, been demonstrated to be capable of yielding sound results in commercial service.

It has been maintained that it is important to devise some method of telling the quality of a weld without subjecting it to a destructive test. Although researches along these lines are in progress, it may be stated unreservedly that while the Welding Research Sub-committee is entirely of the opinion that reasonable efforts should be made to develop some effective method of examining welds without destroying them, nevertheless the evidence coming from all directions to the effect that the welding art is by no means a novelty, but is thoroughly established and reliable, is leading to the belief that (just as in the case of masonry constructions, for example) entire reliance can justifiably be placed upon the soundness of the work of skilled craftsmen when engaged under the direction of trained inspectors.

Actual Application in Ship Construction

The technical press has given such wide publicity to the welded barge which the British Admiralty has built and which has now crossed the Channel many times, that it is unnecessary to direct further comment thereto. Based upon the very satisfactory results in this instance, the British Admiralty and Lloyd's Register are making progress in the construction of further welded ships of greater size and other types. The Welding Research Sub-committee is unanimously of the opinion that there is a super-abundance of evidence justifying proceeding at once with the construction of welded ships, and there is now every reason to believe that before Great Britain has many more welded ships in service at sea, the keel for a large welded ship will have been laid in an American shipyard.

The First Electrically Welded Boat

By John Liston
Publication Bureau, General Electric Company

A great deal has been published in the technical press about the electrically welded cross-Channel barge recently built in England, and now in service. It will be a source of much satisfaction to American engineers, however, to learn that the first electrically welded boat was built three years ago at Ashtabula, Ohio. In view of the meager amount of information on the subject of electric welding that was then available, the employment of the process in the construction of this boat was epoch making; and that the work was well done and the process is peculiarly adapted to shipbuilding are evidenced by the service record of the boat. It has been put to unusually severe service, has suffered one bad accident, and yet at no time has it developed leaks in the electrically welded seams. The boat is still in use on the Great Lakes.—Editor.

Frank Geary

THE present intensified activity in shipbuilding, born of our war necessities, has caused renewed interest in the investigation of electric welding and in the possibilities of its adoption for various phases of ship construction work. As a result, numerous tests of both theoretical and practical value have been made, reported on in detail, and exhaustively analyzed.

While the consensus of competent opinion has long been in favor of a very considerable application of electrical welding for repair work on shipboard, the logical development of a complete system of welding for ship construction has also been recently undertaken and, providing the welding operations are properly performed, this process will undoubtedly effect a reduction in the time, material, and labor required as compared with present methods.

In order to secure a practical demonstration of the correctness of these claims, there was launched in June, 1918, a 275-ton, English built, rivetless welded barge, intended for cross-Channel service. The hull was rectangular in cross section amidships, with only the bilge plates curved. The plating was $\frac{1}{4}$ in. and $\frac{5}{16}$ in., and all the joints were lap-welded.

At that time it was not generally known that for more than two years prior to the completion of this barge, an American built welded boat, Figs. 1, 2 and 3, had been plying the waters of Lake Erie.

As the hull plating of the American boat was butt-welded, in contrast to the lap welding adopted for the English barge, the two craft give supplementary evidence of the general adaptability of electric welding for shipbuilding.

The launching of the American boat occurred three years ago at Ashtabula Harbor on Lake Erie. It is a 42-ft. steel craft which was built very largely by metallic electrode welding and has since successfully withstood the test of practically continuous daily service. This boat, the *Dorothea M. Geary*, was built by its owner, Mr. Frank Geary of the Geary Boiler Works, Ashtabula, Ohio. The keel, frames, and deck house are riveted, but the seams of the hull and the fore and

Fig. 1. Side View of Electrically Welded Boat

aft deck plates are all electrically butt-welded.

Without previous experience as a boat builder and without drawings, but backed by three years of success in electric welding repair work, Mr. Geary, with the aid of three assistants, constructed the boat by empirical methods from the model (Fig. 4) in a period of about 80 days; devoting only their spare time to the work, so that no record is available of the time actually expended.

The dimensions of the craft are: over-all length 42 ft., beam 11 ft., molded depth 6 ft. 6 in., draft 40 in. The angle iron frames (Fig. 5) are $\frac{1}{4}$ in. by $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. and are spaced 18 in. apart.

The keel is of 1 in. by 5 in. steel, made up of three pieces welded together, and to this the single piece sternpost was in turn welded. These three welds rendered it possible to provide the boat with a strong, smoothly finished, single piece keel structure by using four short and comparatively inexpensive pieces.

For the hull and deck plating No. 8 steel in sizes 4 ft. by 8 ft. and 4 ft. by 10 ft. was used.

It was fully understood at the time that thicker plating would have been desirable, but the necessity for economy determined the use of the light steel which is slightly less than $\frac{3}{16}$ in. thick. This point should be kept in mind in connection with the rough treatment (which will be referred to later) to which the boat was unavoidably subjected, by accident as well as in the ordinary course of service.

The steel plates were fitted to the hull, trimmed where necessary by means of a hand shear, and adjoining pieces were held together temporarily by holding bolts, or clamps, or both, until the welds were completed. Where a few of the vertical welded seams were located between the frames, reinforcing riveted straps were used inside the hull to prevent the light metal from buckling; but the remainder of these vertical welds, and all the longitudinal welds, were unsupported in any way except that, as before stated, the hull plating as a whole was riveted to the frames and keel. The spacing of the frame rivets is shown in the lower part of Fig. 5.

When the plates were in position the seams were V'd out with a pneumatic tool, and the weld was built up from the bottom of the V

Figs. 2 and 3. Bow and Stern Views of Electrically Welded Boat with a metallic electrode, the current at starting being about 150 amperes at 50 volts.

An analysis of the electrodes used shows a carbon content of 0.10 per cent, manganese 1.87 per cent, and a trace of silicon. There did not appear to be any chromium, vanadium, tungsten, or nickel present, and there was not available a sufficient sample of the material to determine its sulphur or phosphorus content. The electrode is therefore apparently of ordinary 0.10 per cent carbon steel.

Fig 4. Model of Hull

The welding was accomplished at an average rate of about two feet per hour. Every effort was made to insure clean surfaces of contact for the electrode, and the completed welds were finally pneumatically hammered.

To those familiar with recent progress in welding the rate at which this work was accomplished may seem rather slow, as welding of a similar nature has since been successfully performed at a speed of about seven feet per hour. The excellence of the results achieved, however, is ample justification for the rate at which the boat plating was welded.

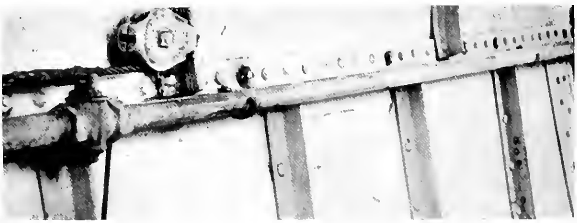


Fig. 5. View showing Frames, Spacing of Rivets, etc.

The welded seams on the boat were not smooth-finished and can be readily traced in Fig. 6, which also indicates the irregular shapes of some of the steel plates used.

In welding the main deck, fore and aft, the same system was utilized. The after deck shows a regular arrangement of plates, but the forward deck (Fig. 7) shows an irregularity in the sizes of the steel plates used which would have rendered it somewhat difficult to utilize them for this purpose if riveting had been required. There are no lap welds in either hull or deck.

The structure above the deck line was riveted and strengthened with angle iron, only a limited amount of welding being applied to this part of the boat to re-enforce corners and to make it watertight. Current and compressed air for the building operations were supplied by a generator and compressor installed in a smaller boat of ordinary construction.

In appraising this pioneer work, it should be borne in mind that it was performed at a time when the information on the subject of electric welding, applied to shipbuilding, was very meager when compared with the voluminous data now available as the result of subsequent investigations. The process itself, for this particular application, was in its developmental stage, and was, in fact, dubiously regarded by a majority of shipbuilders.

The sole purpose in building the welded boat was to secure a complete, self-contained, mobile electric welding outfit which would enable the owner to take care of increasing demands for marine welding repair work, and to insure the ready transportation of the equipment to the work, practically regardless of weather conditions.

The decision to weld the plating was based simply on the builder's confidence in the strength of electrically welded joints, when properly made, and in his ability to produce economically, by this method, a strong and permanently watertight hull. The service record of the boat to date has fully justified this confidence.

About the end of November 1915 the completed hull was launched and the combined propelling and welding equipment was installed. No formal trial trip was made, the boat being placed in service at once in Ashtabula Harbor.

The equipment, which is shown diagrammatically in Fig. 8, is all located symmetrically along the center line of the boat. It comprises a 50-h.p., 4-cylinder, 375-r.p.m. gasolene marine engine, placed approximately amidships, which gives the boat a speed of about 10 miles per hour, forward of this and connected by a silent chain drive to the engine shaft is the generator, which is rated 12½ kw., 70 volts, 220 amp., 600 r.p.m. The switchboard has the usual instruments, rheostat, switches, etc., and is mounted just in front of the steering platform, from which point the engine and the propeller shaft gears are also controlled. The boat, when running, can therefore be handled by one man.


Fig. 6. Port Bow showing Irregular Shapes of Hull Plating and Electrically Welded Seams

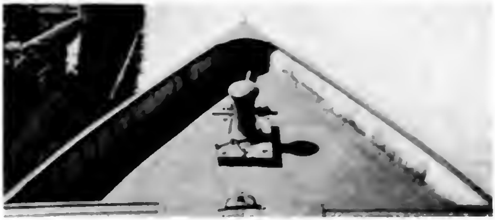


Fig. 7. View of Forward Deck showing Irregular Shapes of Plating and Electrically Welded Seams

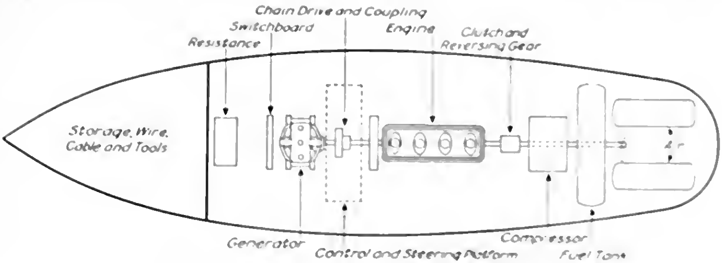


Fig. 8. Plan of Welded Boat showing Location of Machinery

In addition to supplying current for welding, the generator is used for lighting, storage battery charging, and for operating the air compressor motor, and is normally left connected to the engine. When making long trips, however, the driving sprocket is uncoupled from the engine shaft.

The motor-driven air compressor has a capacity of 50 cu. ft. per min., giving pressure up to 90 lb. for chipping, riveting and drilling tools, and the three air storage tanks, two of which are indicated in Fig. 8, have a combined capacity of about 300 cu. ft.

If this craft had been run only in quiet or sheltered waters her three years record of operation would still be of considerable interest as an indication of the value of electric welding for ship construction, as during that time no leaks have occurred in the welded seams and none of the welds have given any evidence of weakening. But this value is strongly emphasized by the fact that at various times the boat has safely undergone treatment which would have proved injurious and probably destructive to a craft of her size built by ordinary construction methods.

On December 17, 1915, shortly after the launching, a call for repair work was received from Fairport Harbor, distant about [illegible] miles, and although the Lake Erie shipping was practically suspended at that time, owing to weather conditions, the welded boat was at once headed into the lake, which was covered with floe ice, and made the run to Fairport in about 3½ hours.

When the harbor was reached it was found to be covered with four inches of solid ice, and into this the welded boat was rammed, breaking her way through, at reduced speed but without a stop, to the pier where the ship she was to work on was laid up.

After the return to Ashtabula a careful inspection of the boat failed to show that any injury had been sustained.

Later, under similar conditions, ice from 8 to 10 inches thick was broken by driving the bow of the welded boat up over the surface of the ice and breaking through it by sheer weight. In this case both the bow and the bilge plates were specially subjected to the

Fig. 9. Electrically Welded Boat Attempting to Break Through Twelve to Fourteen-inch Ice

heavy impact of the broken ice, and as a result the light steel plating and some of the frames were bent; but, as before, the welded seams held.

In a subsequent attempt to crush through ice from 12 to 14 inches thick, the boat was driven up on the surface as shown in Fig. 9, and as its weight proved to be insufficient to break through, it had to be released by cutting and blasting the ice.

During the progress of work on ships laid up in port for the winter, it was several times found necessary for the welded boat to serve as an ice breaker, and the consequent severe torsion and bending stresses caused a number of leaks in the hull, all of which were found to occur at rivet holes.

In the following year an accident occurred which threatened to destroy the welded boat. Work was being performed aboard the freighter *Alexis Thompson*, in the Superior slip at Ashtabula, the welded boat lying alongside as shown in Fig. 10, when the freighter *C. Russell Hubbard*, which was moored at the opposite side of the slip, broke adrift, swung across the slip, literally squeezing the small craft between the two large freighters, both of which were loaded with ore.

The effects were, quite naturally, rather serious, the sides of the welded boat being crushed into a maximum distance of 18 inches amidships, while the deck house roof buckled upward about 6 inches. This damage was repaired by means of jacks which were used to force the sides back into normal position.

Leaks were started but investigation showed that they were again due to loosened rivets and not to any failure of the welds, and it is significant that rivets, when removed at various times, were not in any instance replaced.

Fig. 10. Electrically Welded Boat Lying Alongside Large Freighter Just Previous to Being Squeezed Between This Freighter and Another Large One

Instead, the holes were filled with electrode metal and welded to the frames.

It is true that the welded boat is a relatively small craft, but it is also essentially a true ship, and, so far as is known, it is the earliest example of practical shipbuilding accomplished by means of metallic electrode welding. The opinion of its builder, as stated to the writer, is therefore worthy of attention by those directly interested in ship construction.

When asked how he would construct a similar boat, in view of his experience with the present one, he replied, "I know more today about boat building and electric welding than I did three years ago, and if I have to build a new boat I will use heavier plating than before; but there will not be a single rivet in it anywhere; the boat will be 100 per cent electrically welded."

Electric Welding in Navy Yards

By Lieutenant Commander H. G. Knox
Construction Corps, United States Navy

What better recommendation can be given the electric welding process than that it is used in the construction and repair of our naval vessels! In the introduction of the following article, the author first outlines the arc-welding and resistance-welding processes as related to their general application in navy yards. Following this preliminary treatment, he considers the work conducted in each type of shop in a navy yard, recommends the kinds of welding equipment desirable in each shop, and illustrates by many photographs the character and variety of the work done. In conclusion, he gives figures of the speed and cost of welding ship structures, and cites, from steam railroad records, comparative cost data of welding and other methods.—Editor.

During the past few years, the extension of welding of all kinds to the building and repair of ships has been phenomenal. This is particularly true of electric welding, which is itself in a very rapid state of development.

Under the head of *Electric Welding* there are several different processes involved, and the term is applied correctly to all methods involving the production of a welding heat by the direct application of electric energy.

Before describing its present applications, and mentioning some of the possible ones of the future, it would be well to classify and describe the principal methods and their uses.

Electric welding has two main subdivisions: *Arc Welding* and *Resistance Welding;* and the method of changing the electric energy into heat is different in the two cases.

Arc Welding

Both metallic and carbon electrodes are used, the use of the former being much more general than of the latter which is confined largely to cutting and to welding thin work not requiring a filler.

The metallic electrode supplies the necessary filling-in material; while with the carbon electrode the filling-in material, if necessary, has to be supplied independently by melting a rod of metal in the heat of the arc. Joints for carbon-arc welding are usually made to be self-filling.

Metallic electrodes are of several different kinds; notably, Bare, Covered, and Coated.

The bare electrode is usually a hard-drawn, low-carbon steel or ingot-iron wire, possessing certain chemical qualities which enable it to function under the conditions used.

The covered electrode differs from the bare in that it has a covering of refractory material, such as yarn impregnated with a flux.

The coated electrode is a bare electrode treated with a viscous liquid, usually a compound of lime or borax in water.

Carbon electrodes are also of different kinds; viz., Plain and Copper-coated, Graphite and Carbon.

For the metallic electrode approximately 20 volts at the arc is required for either alternating or direct current. In the case of the carbon electrode, 30 to 40 volts at the arc is necessary. In order to obtain a stable arc and satisfactory results, it is desirable to have a generator of such characteristics that an increase of voltage at the arc is accompanied by a corresponding decrease of current, and vice versa. It is further desirable that the circuit have a certain amount of inductance tending to smooth out any irregularities in sudden current changes, and to assist in the maintenance of the arc.

Many machines containing patented features have been placed on the market, but the tendency at the present time is towards the simplest form of equipment, and preferably of the type known as "variable voltage" or "constant energy." A machine of this type gives from 40 to 70 volts on open circuit and approximately 20 volts at the arc with any current setting required for the work at hand.

So far, the equipment offered by various manufacturers for alternating-current arc welding has not proved as satisfactory as the direct-current equipment. There does not appear, however, to be any inherent objection to the use of alternating current, providing the equipment fulfills the fundamental requirements of electrical apparatus. There is no doubt that it takes greater dexterity on the part of the operator to maintain an arc with alternating current, this being particularly true when overhead work is being done.

The continuous magnetic field, absent in alternating current and present in direct current, helps the deposition of the metallic particles of the electrode into the weld, whether above or below the electrode tip. Its absence in alternating current makes the use of this form of energy slightly more difficult

Concerning alternating-current equipment, attention might be directed to the low power-factor of this type of apparatus, and makers are wont to omit this point in advertising.

Resistance Welding

The successful field of alternating current has, up to the present, been in resistance welding. The term "resistance welding" is a very appropriate one, and should be used more than it is.

The pieces of metal to be welded are placed in contact between terminals, and a heavy current is passed through them on a desired spot or line. Upon reaching a welding temperature, the application of pressure completes the weld. The terminals of the spot welder are copper points, and those of the line welder are copper rollers.

Another machine which is of interest under this heading is the butt welder; this is designed to handle special fittings in the form of bars, rods, pipe, etc. The terminals of the butt welder are suitable clamps to hold the work, and these are made of hollow copper, water-cooled, and generously proportioned for conducting the current.

There are several modifications of the foregoing methods applicable to certain classes of work, particularly where additional means of localizing the heat are necessary. The insertion of disks or buttons in heavy plate seams is an example known as "button welding."

Resistance welders are merely single-phase transformers having a secondary of one or two turns, the voltage required between terminals being only 5 to 10 volts. The current, however, may run to 100,000 amperes or more.

While electric welding has been used chiefly for steel, the technique of the art for cast iron and the various non-ferrous alloys used in ship building is being rapidly developed.

The welding of copper* can be very successfully done with the carbon electrode, although, as a substitute for brazing, gas welding to date is more generally employed on this metal. Brass* and bronze castings and flanges welded to pipe are very common.

* The electric butt welding of the copper and brass rotor bars and end rings of squirrel-cage induction motors is described in "The Butt Welding of Some Non-ferrous Metals," page 958 of this issue.—Ed.

The gas welding of cast iron is, generally speaking, superior to arc welding in strength, reliability, and machinability. Gas welding, however, requires preheating, and either the placing of the weld so that the work is flat or the use of carbon blocks and paste on vertical work. This often precludes the possibility of using the gas torch. For overhead welding, or when the casting is too complex to make preheating advisable, resort must be had to arc welding. Overhead gas welds are seldom attempted.

All Navy Yards of the United States now have their electric welding equipment, and at some of them quite a number of operators are daily engaged in new and repair work. The field for its use in both Merchant and Navy Yards is almost unlimited. As a saver of time and money there is no single industrial "tool" that can compare with it.

Navy Yards are essentially repair stations for the structural hulls with their myriad types of mechanical equipment, and perhaps represent, under single management, as great, if not a greater, variety of trades than found in any other business.

Fig. 1. Main Engine Casting showing Cracks which Developed in Service. Repaired by electric arc welding

Welding Shop

The center of welding activity in the Ship or Navy Yard will undoubtedly be the welding shop. This shop will be, at least in a repair yard, essentially a jobbing shop called upon to do welding of all varieties with gas and arc; and will probably be, at the same time, the reservoir for trained welders for other shops and the authority on welding and welding equipment of all sorts.

To detail the pertinent activities of this shop would be impracticable, but, generally speaking, all miscellaneous work removed from vessels for welding and all work in shops not especially provided with welding equipment will be handled here. A foundry, for example, will undoubtedly be given both arc and gas welding equipment, while a machine shop will hardly be so equipped. The principal use of arc welding in connection with a machine shop is in the nature of a "putting-on" tool to build up forgings and castings originally produced undersize, or to add material inadvertently machined off.

A typical welding-shop job is illustrated in Fig. 1. This main engine casting embraces in the center a high-pressure cylinder, on the right a high-pressure valve chest, and on the left an intermediate valve chest. The receiver connecting these two valve chests is an integral part of this complicated casting and

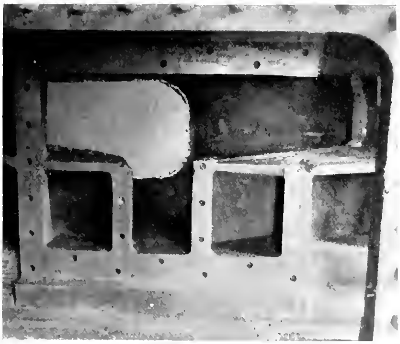


Fig. 2. Another View of Main Engine Casting shown in Fig. 1. The hole in the cylinder wall was cut through to facilitate welding the steam port wall.

passes through the pedestal shown in the center foreground. The complexity of this cylinder can be well imagined.

In service, not only did the cylinder develop cracks, as shown in Fig. 1, but the walls of the steam passages were also broken beyond repair, as shown in Fig. 2. That expert "surgery" must be applied to jobs of this nature is indicated by the hole in Fig. 2 which was cut through the main cylinder wall in order to effect the welds on the steam-port walls. Due to the complexity of this casting and to the danger involved in preheating, all the welding was done by the electric arc.

Fig. 3. Broken Gear Wheel Being Prepared for Electric Welding

The welding shop is invaluable in the repair of shop tools, as well as the breakdowns of ship equipment. Fig. 3 represents a toothed segment broken from a large lathe. This iron segment was recast and arc welded in place.

Fig. 4 shows another almost daily application of welding to ship work. This cast-iron propeller was actually repaired by gas welding, but repairs to propellers are frequently made by electric, as well as gas, methods.

Fig. 5 illustrates additional varieties of arc welding, pieces *1*, *4*, and *6* being clearly within the province of the welding shop. Pieces *2*, *3* and *5*, in this instance, were welded by the boiler or tank shop.

Piece *6* is a steel thimble for 10-inch circumference manila rope. In the olden days this was laboriously forged by hand in one piece. Dies have recently been made for stamping out various sized thimbles. The thimble is finished by welding the two halves together as shown.

Fig. 6 represents an interesting example of built-up journals where too much metal had

Fig. 4. Damaged Cast-iron Propeller Repairs of this kind are effected daily by electric arc welding

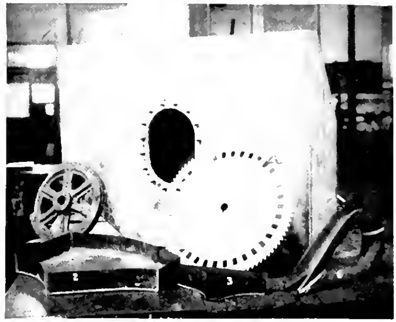


Fig. 5. Some Applications of Electric Arc Welding to Construction

been removed in machining. These crank shafts, for standard navy gas engines, were picked up by the inspector as undersize and were saved by welding as illustrated.

In a repair yard the need for building-up is perhaps as commonly encountered as the actual welding of breaks. Fig. 7 represents a large, low-pressure piston for a merchant ship in the process of being built up. In service, a cylinder liner becomes worn and requires reboring to true it up. When this is done, the diameter of the piston must be increased before turning to fit the new bore.

The equipment of the welding shop should be most generous. In addition to a complete gas welding and cutting outfit, the installation should include a special cast-iron welding floor grounded to one terminal of a

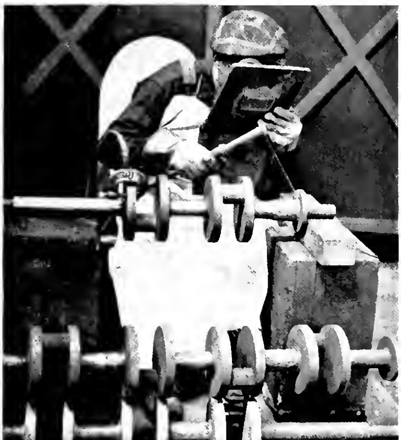


Fig. 6. Building up Incorrectly Machined Crank Shaft Journals by Electric Welding

Fig. 7 Building up a Large Low-pressure Piston by Electric Arc Welding

Fig. 8. Steel Plate Riveted to Casting, the Seams Being Closed by Arc Welding

Fig. 9. Two Steel Stem Forgings, One of Which Has Been Electrically Welded and the Other is Ready for Welding

Fig. 10. Steel Hatch Covers for Small Vessels. The corners are electrically welded

Fig. 11. Large Tank with Electrically Welded Seams

large arc-welding generator or else conveniently arranged for putting in the smaller one-man machines.

Butt- and spot-welding machines of the resistance principle will seldom be required for the jobbing repairs encountered in this shop.

Structural or Shipfitter Shop

The structural shop in a Navy Yard handles all of the structural steel hull work, embracing the fabrication and erection of the ship hulls proper and all the subdivisions thereof.

The Emergency Fleet Corporation Committee on Welding is at present carrying out an exhaustive study of gas and arc welding in order to demonstrate their adaptability to the building of ship hulls. In England, a cross-Channel barge completely arc welded is already in service and several smaller vessels have been laid down. In the United States, one or two vessels are now being welded and it is hoped in the near future to undertake the complete welding of a steel cargo ship larger than has been attempted heretofore in any country.

The welding of the hull proper, while involving an enormous amount of welding, will not present any intricate problems comparable with the daily jobs handled in the welding shop. The material welded by the structural shop will be essentially medium steel plates, shapes, forgings, and castings of quality readily suited to welding.

Fig. 8 represents a steel plate riveted to a casting, the seams of the plate having been closed by arc welding.

Fig. 9 represents two steel stem forgings, one arc welded and one fully prepared for welding.

Many of the component parts of ship structures previously built up of plates and shapes can be much more readily manufactured of welded construction. Fig. 10 represents a number of steel hatch covers for small craft. These are notched in the corners, the edges turned up, and the corners then welded. This type of construction has proved very satisfactory and represents an appreciable saving in weight over previous methods. Incidentally, the saving of weight in ship construction is a most vital factor. To the building designer the matter of weight is of little importance; to the naval architect, however, the saving of weight by every known means is an essential consideration of design.

Fig. 11 illustrates a large ship tank, a product frequently required of the structural shop.

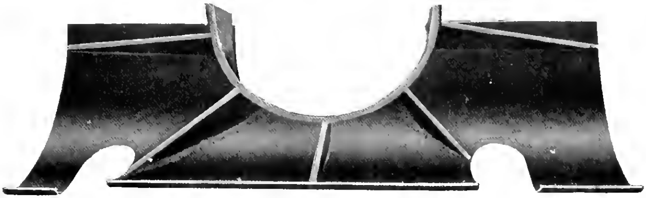


Fig. 12. Part of a Modern Spray Shield for Destroyer Guns. Electric welding gives light weight construction impossible with riveting

Fig. 12 shows part of a modern spray shield as fitted to destroyer guns. A shield with the light weight inherent in this construction would have been impossible if rivets were used.

The equipment of a structural shop for modern shipbuilding will include the installation of both spot and arc welders. Spot welders capable of welding plates an inch thick* are already in contemplation, and the commercial welding of the more common ½-inch and ⅜-inch ship plates will be general in the near future. The arc welding equipment of the structural shop will consist of a large number of machines and outlets in the shop as well as a large number of portable equipments for erection work on the ship.

As the art of welding develops, we may expect to see small portable welders rapidly taking the place of the riveting hammers and pneumatic drills now used by the thousand in ship erection.

* Such a machine is described in "Research in Spot Welding of Heavy Plates," page 919 of this issue.

Sheet Metal Shop

Nowhere in the shipbuilding industry is the field for welding as great as in the sheet metal trade. Thousands of parts of ventilating ducts, light metal bulkheads, tanks, lockers, and similar articles enter into the construction of every ship. Perhaps to the layman no article is more typical of a ship than the ventilator cowl illustrated in Fig. 13. It is here shown as cut out and built up in segments, also assembled and galvanized ready for installation.

Tanks for oil, gasolene, water (both fresh and salt) are innumerable aboard ship and are made in large quantities of welded construction, as shown in Fig. 14. A variety of miscellaneous sheet metal articles are shown in Fig. 15.

In sheet metal work, the field is not by any means restricted to arc welding, for the spot welding of both black and galvanized sheets is readily possible. The spot-welding machine may be further adapted to a variety of uses, one of which is shown in Fig. 16 in which an ordinary spot welder equipped with a copper jaw clamp and a locating jig is used for welding studs around the opening in a mine. The opportunities for extending this type of weld to all manner of sheet metal work requiring studs are manifest.

The sheet metal shop usually handles work up to $\frac{1}{8}$ or $\frac{3}{16}$ inch in thickness. The equipment of this shop will, necessarily, include a number of spot-welding machines of both short and long gap. The use of a special butt welder will hardly be required, although one or more line welders of a type suitable for general work will be found convenient. The arc-welding equipment of this shop will doubtless be extensive, the carbon electrode being used for the light work and the metallic electrode for the heavy work of the trade. The mechanically driven arc, common in transformer and oil-switch tank construction, bids fair to revolutionize existing methods.

Plumber Shop

The plumber shop, more correctly called the "pipe shop," is organized to handle both steel and copper pipe and tubing for water, steam, and oil. In addition, the plumber shop will naturally handle a great variety of articles built up of pipe, valves, and similar fittings. The use for welding in this shop is rapidly extending, so that practically all pipe work, including the welding of branches, bosses, and flanges to any pipe, may be safely and expeditiously done by welding.

The welding of copper is now quite common. Copper pipe rolled up from a flat sheet with welded flanges and seams is in use, the flanges being made from scrap brass instead of brazing metal.

Gas welding has, to date, been generally used on copper, but the field for the arc, using the carbon electrode, is rapidly being explored. Fig. 17 shows a number of small welded fittings pertaining to the plumber shop. The bent pipes in the foreground are copper intake manifolds and water service pipes for use on Navy gasolene engines.

The plumber shop requires the installation of both arc- and gas-welding equipment. At many of the Navy Yards a gas generating plant for oxygen, hydrogen, and acetylene is operated by the foreman plumber and is located in or near the plumber shop. The three gases are compressed and distributed through pipe lines to the various welding stations. This in combination with a welding generator, the size of which is dependent on the number of operators desired, forms an excellent equipment. Usually, inasmuch as the welding is performed on pieces of relatively light weight, cast-iron slabs or metal benches are preferable to a heavy welding floor.

Forge Shop

A modern forge shop, replacing the blacksmith shop of the past, includes many types of machines until recently unfamiliar to the smith.

At the Navy Yard, Norfolk, Va., a modern forge shop is nearing completion. In this shop are installed forging presses of three hundred, eight hundred, and two thousand tons, in addition to the many large and small steam hammers heretofore employed. The drop-forge plant will have twelve hammers and a large number of bolt and rivet making machines, also one or more electric butt welders of a capacity for welding $1\frac{1}{2}$-in. diameter round bars or any metal of equivalent section. Fig. 18 illustrates some of the preliminary products of this machine. Tee wrenches are quickly made and, with special dies, angle rings may be welded in a few seconds.

Other terminal clamps readily adapt the machine for welding chain links, also illustrated in Fig. 18. An order for 24,000 rowlock sockets for boats was recently received. In the past these have been made from scrap

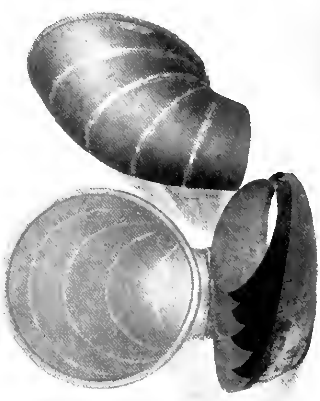


Fig. 13. Ventilation Cowls, the Sections of which Are Electrically Welded Together

Fig. 14. Tanks of Various Sorts, the Seams of which Are Electrically Welded

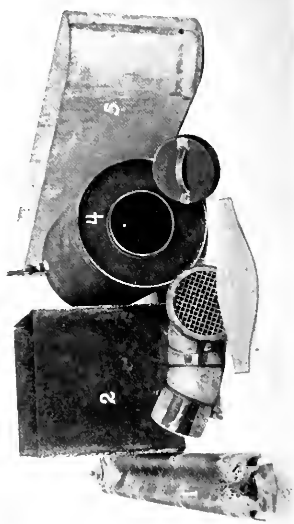


Fig. 15. Miscellaneous Sheet Metal Parts on which Electric Welding is Employed

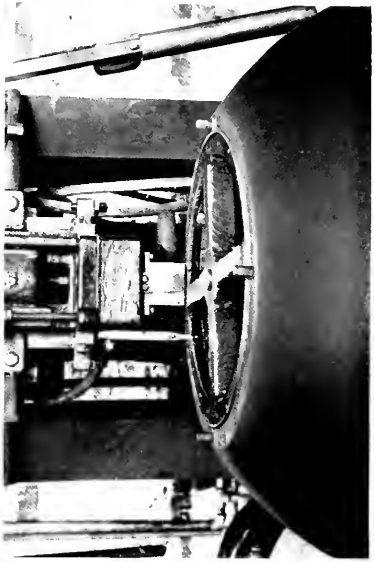


Fig. 16. Spot-welding Machine Welding Studs to a Naval Mine

brass in the foundry. In the foreground of Fig. 18, immediately behind the welded ring, this socket is shown before and after welding. The flat plate is blanked, punched, and the center hole formed at one press operation. To this plate is butt welded a short section of pipe. After welding, the slight upset at the weld is removed by a milling tool and the finished socket is galvanized ready for installation.

With the present shortage of high-speed steel, few machine shops can afford the luxury of solid, high-speed tools. The welding of high-speed steel to low-grade tool steel bodies requires some experience, but once the technique is mastered the method is invaluable from the standpoint of economy.

High-speed twist drills are also successfully butt welded. In a test, a 2½-inch welded drill was driven in a large drill press until the machine stalled, thus demonstrating the strength of the weld.

The possibility of salvaging drills and other expensive tools is unlimited.

Boiler Shop

The shipyard boiler shop differs in no essential particular from the boiler or tank shop of a railroad insofar as the kind of work is concerned. Boiler welding by electric arc is almost as old as the art of arc welding itself and is perhaps one of the most generally known of its adaptations.

Navy Yards and also other marine yards perhaps cover a wider variety of types of boiler than any other establishments. Many a Scotch boiler shell, tube sheet, furnace, and combustion chamber has been successfully built up or patched by the arc. Tubes themselves are pieced out by butt welding or the judicious use of the arc. Water-tube boilers, too, come in for their share of attention by welding.

In this class of work, most often done under the extremely trying handicaps of location on board ship, the maximum of patience and skill is required of the operators not only as welders but also as practical boilermakers. Flat, horizontal, vertical and overhead work is "all in the day's work" with these journeymen—"journeymen" in the most literal sense of the word.

Portability is probably the most important single feature of boilermakers' welding machines. Single-operator units, often gas-engine driven are very useful, particularly where the source of power on the ship under repair is doubtful.

Foundry

The foundry and forge shops are the two main contributors to the other shops of a manufacturing plant. Navy Yard foundries pour not only cast iron and steel but numerous non-ferrous alloys. Defective and broken castings in all of these metals are successfully repaired by welding. The general practice is to use gas welding for cast iron, brass and bronzes, restricting the use of the arc to cast steel. Fig. 19 shows a large pair of cast steel bitts. When shaken out of the sand they were found to be entirely unfit for use on account of a shrinkage crack at the base. This casting was arc welded and, while perhaps an extreme case, is illustrative of the value of arc welding.

Porous spots and small blow holes are readily filled in castings before they leave the foundry, thus often preventing the scrapping of them after considerable machine work has been done. The economy resulting from the saving of castings is difficult to estimate as it represents not only the money involved but very often permits the use of an emergency casting, unfortunately cast defective, the lack of which would delay the sailing of a ship.

The electric arc and the gas torch have made possible the cutting of steel of any shape. Of the two, the arc is undoubtedly the more economical and on account of this and its flexibility its use is preferable. On the other hand the cut made with the gas torch is much smoother. If the oxy-hydrogen flame is used, armor plate 24 inches thick can be cut. Fig. 20 shows the scrap pile in a foundry yard and an operator at work preparing structural steel scrap for charging into the electric furnace.

Conclusion

The rate at which the edges of two plates can be joined is not the only economy effected in arc welding a ship structure. When riveted construction is used, the plates must be laid off from templates, every rivet hole marked and center-punched even before the plate reaches the fabricating shop. In the shop the holes are punched or drilled, the plate sheared, and then sent out for assembly in the finished structure. After bolting in place, it is necessary to ream many holes before they can be filled with rivets. After driving the rivet must be tested and later every rivet head and inch of seam caulked for water-tightness.

In welding, the plate is merely sheared to size, the edge being automatically beveled

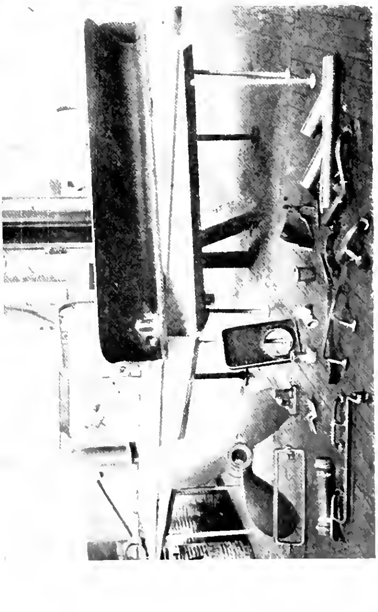


Fig. 17. Small Welded Fittings from the Plumbing Shop

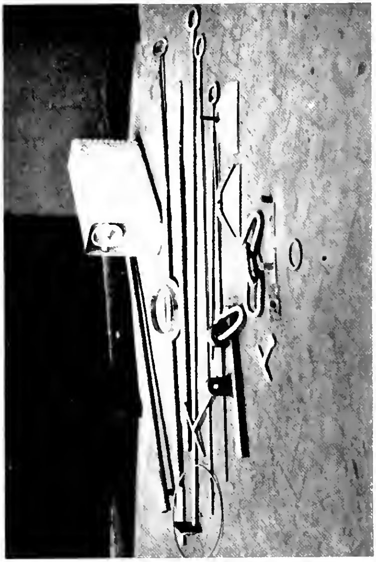


Fig. 18. Production of Electric Butt-welding Machine

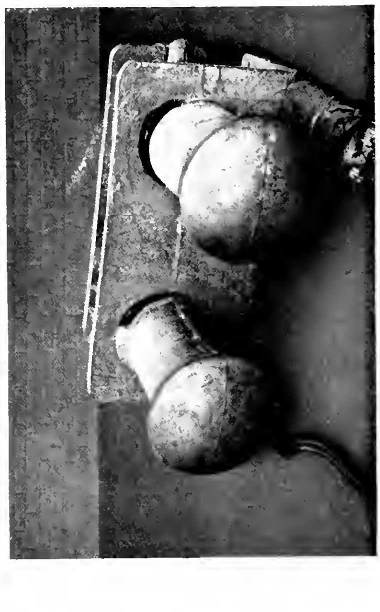


Fig. 19. A Pair of Large Cast Steel Bits Cracked in Casting and Repaired by Arc Welding

Fig. 20 Scrap Pile showing Use of the Electric Arc for Cutting

by the rotary shear at the same time. A few holes for erecting bolts may be necessary but otherwise the plate is free from holes when delivered to the ship. On the ship, the edge is rapidly welded and will be tight not only for water but even against the searching penetration of oil.

The speed of welding a ½-in. plate is approximately 3 ft. or more per operator per hour. A little over ½ lb. of electrode per foot of weld will be required, 15 per cent probably being lost as waste ends, etc. It is estimated that about 30 lb. of electrode, costing perhaps $5, is required per ton of structural steel. The labor will probably average $15 per ton and about 2½ kw-hr. per pound of metal deposited is necessary. This gives $1.80 as an approximate cost of power for welding one ton of structure.

At the Pittsfield Works of the General Electric Company a 12-ft. cubical tank,* made of ½-in. plates, was recently constructed, eighteen types of joint being used. The official report of this test which was very rapidly conducted is of value as it gives authentic figures for this kind of plate work. Power was supplied at 75 volts, direct current, and the average current used by each welder was 150 amperes. The following is a summary of the results:

Total lb. of electrode	334
Waste ends and scrap, lb.	35
Average per cent loss	11
Metal deposited, lb.	299
Total feet of weld	501
Total welding time, hr.	165
Kilowatt-hours	1011
Lb. of electrode per ft. of weld	0.60
Kw-hr. per lb. of wire deposited	3.4
Average feet of weld per hr.	3.0
Kw-hr. per ft. of weld	2.0
Per cent of time welder actually welding	66.0
Diameter of electrode, inches	0.188

Total labor and material cost, including preliminary fabrication, was approximately $1,000 and the weight of the steel 16,000 lb. The cost of welders and helpers was approximately $150.

Much has been published by the various authorities on the economy resulting from arc welding. Perhaps no other industry has more extensively used and profited by welding than the railroads of the United States. Mr. E. Wanamaker of the Chicago, Rock Island and Pacific Railroad gives the following comparison of arc-welding versus other methods, which is illustrative of the savings which may be expected.

Description of Parts	Cost of Other Methods	Cost of Electric Weld	Saving	[illegible]
Pedestals	$615.00	$15.24	$599.76	5
Tank frames	9.03	1.36	7.67	1
Shop tools	34.36	3.40	30.96	4
Piston rods	78.64	16.37	62.27	10
Sharp flange drivers	165.40	20.28	145.12	3
Truck side	194.00	10.20	183.80	4
Building up driving axles	121.50	4.90	116.60	1
Steel car underframe	11.34	1.71	9.63	1
Building up car axles	315.00	25.24	289.76	
Bushing staybolt holes	294.96	73.74	221.22	26
Welding flues	2607.65	521.53	2086.12	302
Frames	931.00	133.28	797.72	11
Cracks in fireboxes	2431.27	297.17	2134.10	92
Total	$7839.15	$1154.42	$6684.7[illegible]	

Closely following the example set by the railroads, the Marine Classification Societies headed by Lloyd's and the American Bureau of Shipping were quick to appreciate the possibilities of welding and have already authorized for merchant ship work the employment of welding on thousands of parts entering into the construction of cargo and passenger ships. As in any new art, the shipbuilders have been slow to realize the economy involved and to date a very small proportion of the work already authorized is being are welded.

The introduction of welding involves the training of operators, the procurement of apparatus, and perhaps above all the education of designers in the adaptability of the methods. Perhaps no better organization for assisting the introduction and development of electric welding exists than the sales organizations of electrical manufacturing companies. It would seem a business opportunity, if not almost a patriotic duty, for these organizations to demonstrate to the shipbuilder the savings which will follow the extensive installation of electric welding equipments.

The United States Navy, quick to appreciate the possibilities of welding, has established research centers and is rapidly arranging for the training of operators. The use of welding can perhaps be carried even further in war ships than in merchant ships, and the Navy, alive to its possibilities, is rapidly organizing to utilize to the utmost the manifold advantages of the art.

* Photographs of this tank are included in the article "Electric Arc Welding in Tank Construction," by R. E. Wagner, p. 890.

Arc Welding in Shipyards

By W. L. Roberts

Fore River Plant of the Bethlehem Shipbuilding Corporation, Ltd

Both resistance and arc welding are employed in shipbuilding. On page 923 of this issue Mr. Winne describes some of the applications of spot welding; and below Mr. Roberts describes some of the applications of arc welding. He first shows how the anglesmiths' work is facilitated by the use of arc welding in the production of staples, and then predicts that the use of staples will soon be abandoned in favor of directly arc-welding together the parts to be joined. Other sections of his article are devoted to descriptions of the application of the electric arc to the construction of water, oil, and air tanks, stacks, condensers, ballast tanks, etc.—Editor.

Lloyds has recently published its tentative regulations for the application of electric arc welding to ship construction. With the publication of these rules, there will shortly follow more active steps in the actual welding of modern size merchant ships.

Fig. 1. Stacks on which Electric Welding is Used to Great Advantage

The regulations allow either butt joints with sufficient butt straps or lap joints; yet the rules seem very much to prefer the lap joint. In practice, however, the lap joint is going to be considerably harder to bolt up than a butt joint. In making the lap joint, holes will have to be punched with close enough spacing to allow the plates to be pulled into place, as is now the practice in riveting. In forming the butt joint, bolts and washers can be used through the opening at the butt and the plates brought into a very even alignment. Practice will very soon tell which is the better joint from a constructional point of view. Insofar as the strength of the joints is concerned, there is very little difference.

Up to the present time, welding has been used but little in the shipyard work of this country. The principal part in ship construction which has been welded for the past year or two consists of the staples which are used to make water-tight or oil-tight joints around frames, girders, or beams as the case may be. A group of staples is shown in Fig. 3. This kind of anglesmith work is very expensive as it is all done by hand. From the photograph can be seen very clearly that part of the anglesmith's work which is done by electric welding. Rivets can be driven through these welds when the staple is put in place and there is no tendency to crack open. Staples of these types are used on all ships but will be dispensed with entirely when electric welding becomes a little further advanced in shipyards. There is no very good reason why the parts to be joined, where a staple is now considered necessary, cannot be welded directly together. When this comes about, there will be many hours saved in making this particular kind of joint.

Figs. 4 and 5 show two types of oil tanks which are electrically welded complete. There

Fig. 2. Electric Welding on Condensers

are no rivets or bolts in them. The bosses for the flange connections are welded in place, thus making a very neat piece of work throughout. Water, air, and oil tanks can be and are being welded in this manner.

Fig. 3 Angle Smith Work Simplified by Electric Arc Welding

Fig. 4 Electric Arc-welded Oil Tank

Fig. 5. Another Electric Arc-welded Oil Tank

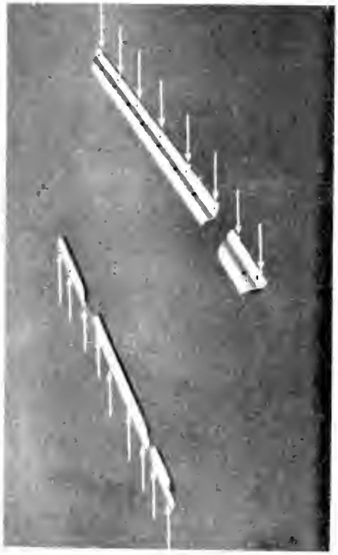


Fig. 6. Method of Attaching Light Bars to Deck Plating by Spot Arc Welding

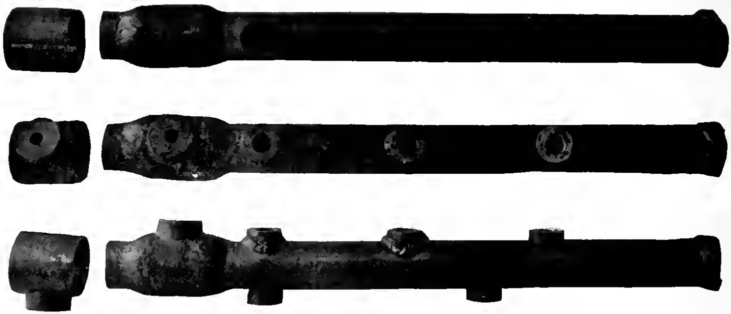
Fig. 6 shows a method of attaching strips of light bars to the deck. These bars are somewhat similar to Z-bars and have holes punched in them about every ten or twelve inches. They are clamped to the deck and the welder makes the joints by welding through the holes, thus forming connections without having holes drilled or punched in the deck. These strips have been placed on over twenty ships and are giving satisfaction. They are used for securing a matting to the deck in order to make walking safer in bad weather.

Fig. 1 shows several inner stacks built in cylindrical courses for ships. The top stack has two courses with double rows of rivets in lap joints. The other courses are lapped but rivets are not used. These laps are spot welded and it is very evident that there is much saving in time when there is no punching or drilling of holes for rivets. The lower two rows of rivets were put in to satisfy inspectors who claimed that this end of the stack, being immediately over the boiler and connected to the uptake, is subject to much more heat. The time is not far off when these stacks will be completely spot-welded as designers and inspectors are rapidly coming to appreciate the advantages of this method of building stacks.

The lower stack in Fig. 1 is the same as the upper stack with the exception that the joints of the courses are butted and a strap put on the inside. In this manner, an extremely neat flush stack is obtained.

Fig. 2 shows the method of electric welding condensers in place of riveting. The welded joints in this illustration show clearly and no explanation is required. This condenser has passed the necessary test required by the inspectors and has been put into actual service. Many more similar ones are being built.

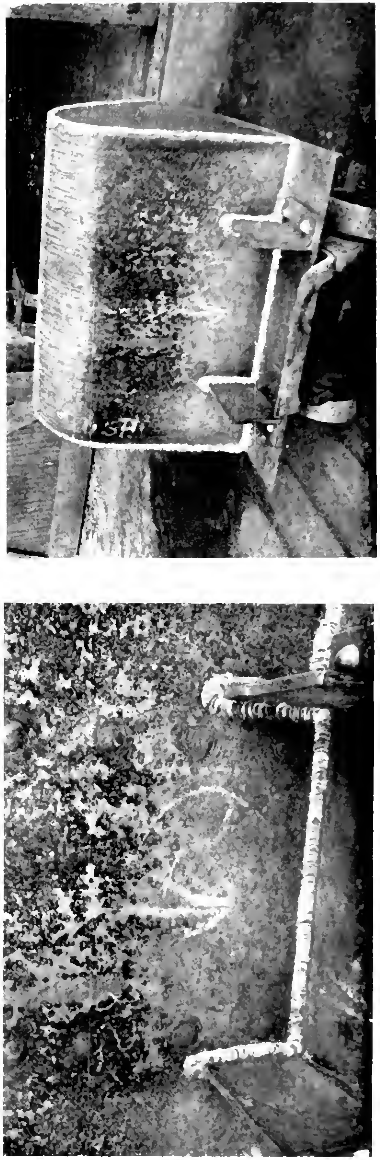
Figs. 10 and 11 show a section model of a submarine ballast tank prepared for electric welding. Figs. 12 and 13 show the tank welded. There are no staples used as stapling on this type of work is unnecessary. This model withstood 185 pounds pressure, which is very much in excess of any requirement for these tanks up to the present time. It was made over a year ago; and yet at the present time staples are still used, due to the over conservatism applied on this type of work. This is one of the parts of ship construction in which there is no doubt electric welding will bring about a great saving in time and result in as good a piece of work, if not better, than has been the practice. What is shown in these few illustrations of this tank will apply to almost every part of a ship for in the tank there are connections of plate to plate and bar to plate.



Figs. 7, 8, and 9. Pipe Joints Constructed by Electric Arc Welding

A unique method of making pipe joints, such as branches in main pipe lines, is shown in Figs. 7, 8, and 9. This pipe is a sample on which two small pieces of pipe were milled to fit the surface of the larger one. These small hollow bosses were first tacked to the pipe, and then were completely welded on the inside thus giving a solid boss on the pipe. They were drilled and tapped; and it was found that the welded metal tapped satisfactorily. The fitting on the left-hand side of these illustrations is a forging made to slip over the pipe and then acetylene welded on, as is seen from the boss on the left end of the pipe. This was the original method of doing the work

Figs. 10 and 11. Section of Submarine Ballast Tank Prepared for Electric Welding



Figs. 12 and 13. Section of Submarine Ballast Tank showing Electric Arc Welding and it is clearly seen how much simpler the new method is. A small bead or run of weld is placed around the outer side of the pipe joint merely for extra strength. It was found on test that this joint withstood 1300 pounds pressure which is far in excess of the requirements. Bosses of this kind are now put on for work in ships at a cost of one tenth the old method.

The details outlined above could be shown in many more ways but are sufficient to demonstrate what is actually being done on ship work today.

Several designs for completely electric-welding a ship have been submitted to shipbuilders. Some of these are good and others better. Designs are now being made to incorporate all the best features. The result will very shortly be an accepted plan from which a ship will be built. In this ship there will be eliminated the many unnecessary bars which are now used only for connecting plates to plates. These plates will be directly electric welded and no bars will be needed. In most cases where bars are needed for strength, the edges of the plates will be flanged to form the strengthening flange of the bar. The entirely electric welded ship is what we may all look for in the near future.

In those yards where the investment for new welding equipments may be considered too expensive at the start, a part-riveted and part-welded ship may be designed. As a rough estimate, more than half the rivets in a ship may be eliminated if only the plates on the shell, bottom, decks, and bulkheads be welded on their edges.

Think about and talk about the completely electric-welded ship. It will be afloat soon. Look for it.

Lloyd's Experiments on Electrically Welded Joints

By H. Jasper Cox

Lloyd's Register of Shipping

The introductory paragraphs of this article set forth the functions of Classification Societies. The remainder of the article is confined to a description of the activities of Lloyd's Register of Shipping in making tests on arc-welded joints for the purpose of determining the acceptability of that type of joint in ship construction. The testing machines employed and the method of performing the tests are described. The complete summary of results of the experiments, which is presented at the conclusion of the article, indicates the reliance which can confidently be placed in the welding process.—Editor.

Few people realize the rôle which a Classification Society of the international standing and reputation of Lloyd's Register of Shipping plays in the development and subsequent commercial success of new ideas in ship construction and marine engineering.

The all too common tendency, even in the profession itself, is to look upon such a society as an existing evil which must be propitiated or cajoled into an understanding and acceptance of new ideas quite contrary to its wishes or desires.

In this connection the writer well remembers a remark made by an eminent electrical engineer who was one of the pioneers in the development of cast-steel anchor chain. The urgent problem of providing a satisfactory substitute to meet the shortage of wrought-iron anchor chain was on the verge of solution by my esteemed friend when he "ran up against" the Classification Societies, "his first serious difficulty." The subsequent history of this particular development, however, and the assistance and co-operation given to its satisfactory solution by the Society undoubtedly disabused his mind.

Of course the main function of all Classification Societies is to provide a definite standard of quality in respect to the strength and seaworthiness of a vessel, and for this they depend primarily upon their actual experience and judgment in such matters. There are, however, two types of Classification Societies. One which has national or sectional interests to serve, and which depends upon such interests rather than upon their professional merit for existence; and the other type which is independent of such interest or control, and which therefore relies wholly upon its professional ability. The former by their nature tend to become arbitrary and hidebound, while the latter must necessarily not only keep abreast of but take a leading part in all development pertaining to scientific and mechanical progress in ship construction and marine engineering.

When, therefore, the development of electric arc welding had reached a state at which its application to the main structure of a vessel, with all the attendant possibilities, appeared a feasible proposition, the Technical Committee of Lloyd's Register of Shipping, quite in accord with its traditions, immediately embarked upon an exhaustive investigation in order to determine at first hand the suitability of electrically welded joints for such work.

The series of experimental tests herein described were devised and carried out under the direction of the Society's Technical Staff in England, extending over a period of many months.

In tests of this nature we must recognize that it is impossible to duplicate the exact conditions which may be met in practice, which conditions in themselves are to a great extent unknown quantities. What can be done, however, is to gauge the general reliability of the proposed innovation by a series of simple comparative tests of various kinds.

The investigations in question were carried out with the quasi arc process of electric arc welding on ordinary mild steel of ship quality, and only highly skilled operators were employed.

NATURE AND DESCRIPTION OF EXPERIMENTS

The general scope of the experiments included:

(I) Determination of modulus of elasticity and approximate elastic limit.

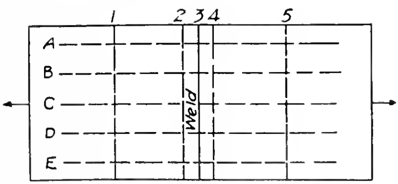


Fig. 1b. Sketch Showing Positions of Readings

(II) Determination of ultimate strength and ultimate elongation.

(III) Application of alternating stresses with:
- (a) Rotating specimens.
- (b) Stationary test pieces.

(IV) Minor tests, such as:
- (a) Cold bending of welds.
- (b) Impact tests of welded specimens.

(V) Chemical and microscopic analysis.

Fig. 1a. Method Employed to Measure Modulus of Elasticity

Tests were carried out on specimens as large as possible, particularly in respect to the static determinations of elasticity, ultimate strength, and elongation, some of the test specimens being designed for a total load

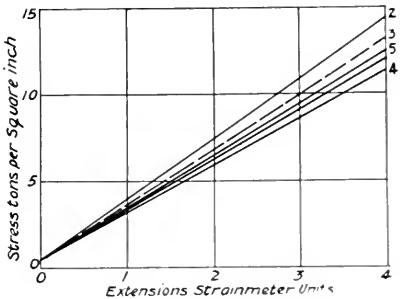


Fig. 1c. Extensions in Direction of Pull, Reading Along Line C of Fig. 1b

of just under 300 tons. The advantage of utilizing large specimens was that the effect of workmanship was better averaged and the results were more comparable to the actual work likely to be met in ship construction.

Fig. 1a illustrates the method adopted to measure the *modulus of elasticity* by means of a strainmeter designed by Dr. James Montgomerie. The photograph shows the holders which were specially designed with a view to

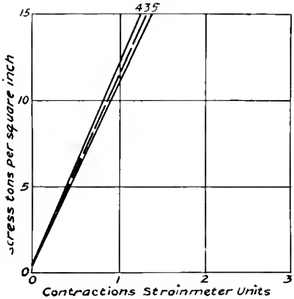


Fig. 1d. Contraction at 90 deg. to Axis of Pull

securing as far as practicable an even pull across the breadth of the plate. Readings were taken in the weld and at various points on the plain plate itself both adjacent to and well clear of the weld, the points at which observations were taken being clearly shown in Fig. 1b.

Typical results, illustrating the extensions as measured along the line C are shown in Fig. 1c from which it would appear that the extensions in the weld do not show any marked difference from those at various spots in the plain plate, the lines showing extensions in the weld lying among the others without disclosing any distinctive features. Measurements were also taken with the strainmeter set at right angles to the line of pull, the readings in this case, of course, representing contractions (see Fig. 1d).

With a view to confirming the foregoing result, a set of specimens of smaller size (Fig. 1e) was prepared and tested. Automatic stress-strain diagrams showing the extensions up to the point of fracture of these specimens are shown in Fig. 1f; while Fig. 1g represents on an enlarged scale the extensions within the elastic limit, the distance between the points of attachment of the instrument being 8 inches in each case. The curves exhibit the same general characteristics as those obtained from the large specimen and would appear to justify the inference that there is very little difference between the modulus of elasticity of the welded samples and that of the plain plate.

With *alternating stresses* the specimens were relatively of small size. For the rotating test pieces, circular rods machined from a welded plate were used, the diameters selected being 1 in. and ¾ in. These bars, about 3 ft.

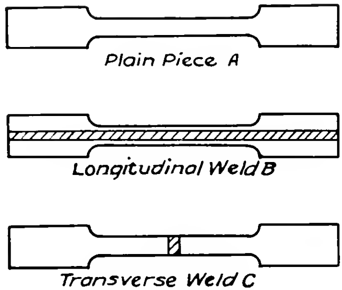


Fig. 1e. Set of Smaller Test Pieces

in length, were attached to a lathe headstock, and a pure bending moment in one plane was applied by means of two ball races to which known weights were attached. The material of the bar was thus exposed alternately to maximum tension and to equal maximum

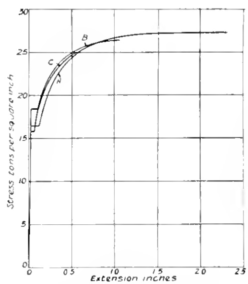


Fig. 1f. Stress Strain Diagrams for Pieces shown in Fig. 1e to Point of Fracture

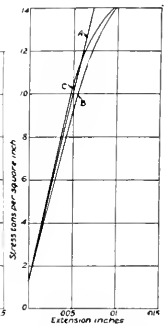


Fig. 1g. Extensions within the Elastic Limit of Test Pieces shown in Fig. 1e Represented on a Large Scale

compression once in each revolution. The machine was run at about 1060 revolutions per minute. Bars of identical material were tried in pairs, one specimen welded and the other unwelded, and the number of revolutions before the specimens parted was observed for various ranges of stresses varying from ± 15 tons to ± 6 tons per square inch.

The general arrangement of the apparatus is shown in Fig. 2a; and a typical example of the results obtained is given in Fig. 2c, which

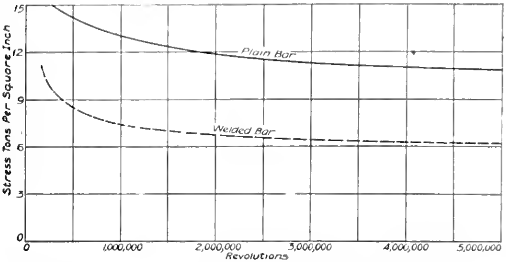


Fig. 2c. Curves Showing the Results of Alternating Stress Tests on Bars

shows clearly the stresses at which the welded and unwelded bars will withstand a very large number of repetitions of stress.

In the second series of *alternating stress experiments* flat plates were used of three thicknesses; viz., $\frac{1}{4}$ in., $\frac{3}{8}$ in., and $\frac{1}{2}$ in. These specimens were tried in groups of four, each group consisting of one plain, one butt-welded, one lap-welded, and one lap-riveted plate. The specimens, which were about 14 in. long by 5 in. broad, were clamped along the short edges so that the distance between the fixed lines was 12 in. Each plate was also clamped near the middle, to the end of a pillar, which by means of a crank arm was caused to oscillate and to bend the specimen equally up and down by adjustable amounts (the maximum total movement in any of the experiments tried was $\frac{5}{16}$ inch). The machine was run at various speeds (not exceeding 90 r.p.m.) and the number of repetitions at which the specimen parted was observed.

The type of apparatus used in these tests is illustrated in Fig. 3a; and typical results obtained are illustrated in Figs. 3b and 3c, in which the ordinates represent total displacement from normal position; i.e., $\frac{2}{16}$ inch means $\frac{1}{16}$ in. up and $\frac{1}{16}$ in. down.

Minor tests of various kinds were undertaken, of which the principal ones had reference to the suitability of the welded material to withstand such bending and shock stresses as

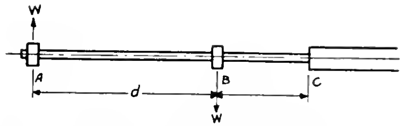


Fig. 2b. Diagrammatic Sketch of Apparatus Shown in Fig. 2a
End A of Bar free, but Supported by Upper Pull W
End C Fixed, the Lathe Revolving at 1060 r p.m.
W = W. Upward = downward. Bending moment between B and C is uniform and equal to W × d.

might occur in the shipbuilding yards. The experiments on bending consisted of doubling the welded plate over a circular bar of diameter equal to three times the plate thickness, and comparing the results with those of the plate of the same material but unwelded.

Fig. 3d shows the results obtained from the bending tests, from which it will be noticed that the angle at which fracture occurred decreases rapidly with increased thickness of plate.

In the impact tests heavy weights were dropped from various heights onto the welded portion of a plate 5 ft long and 2 ft. 6 in. in breadth, the weld being across the plate parallel to the shorter edge. The deflections were noted and the condition of the weld was examined after each blow.

Fig. 2a. Arrangement of Apparatus for Making Alternate Stress Tests on Bar Specimens

Other tests to determine the relative value of welding and caulking under tension and the relative bearing value of a riveted or welded lug attachment are shown in Figs. 4a and 4b. In the former, two plates are attached at right angles by an angle lug with closely spaced rivets and the angle caulked

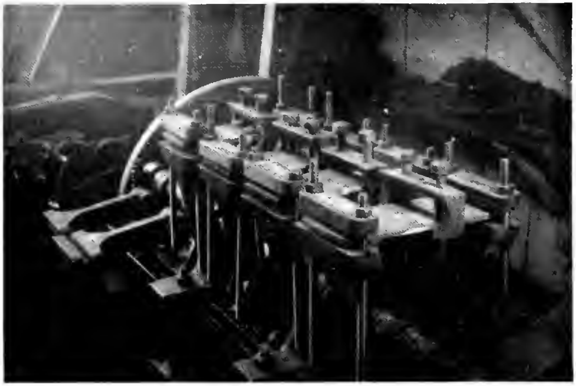


Fig. 3a. Arrangement of Apparatus for Making Alternating Stress Tests on Flat Plate Specimens

on both edges, similar to the boundary angles of a watertight or oiltight bulkhead. The object of the test was primarily to ascertain at what stress the "tightness" of the attachment was destroyed as compared with that of the welded attachment. The results indicated are very striking.

The test shown in Fig. 4b, in which a direct shearing force was applied to the lug attachment, indicates the relative values of riveting and welding a lug attachment for bracket connections, etc. It will be observed that the welded lug is notched out at its mid length and the welding applied only at the ends and in way of the notch.

Many other practical tests of this nature were made but the foregoing are perhaps of greatest interest.

The chemical and micrographical examination followed the ordinary practice.

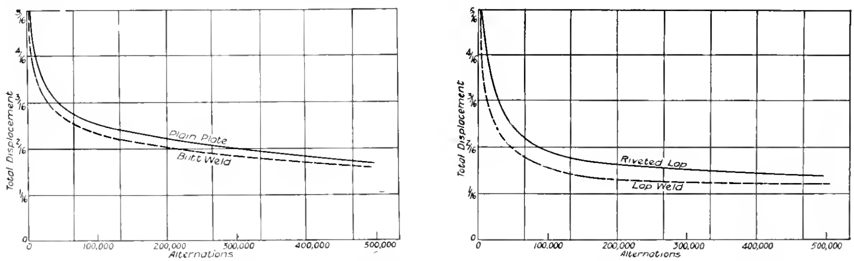
SUMMARY OF EXPERIMENTAL RESULTS

I. Modulus of Elasticity and Approximate Elastic Limit

(*a*) In a welded plate the extensions in the region of the weld are sensibly the same as for more distant portions of the unwelded plate.

(*b*) With small welded specimens containing an appreciable proportion of welded material in the cross-sectional area, the relation between extension and stress is practically the same, up to the elastic limit, as for similar unwelded material.

(*c*) The elastic limit (or the limiting stress beyond which extension is not approximately directly proportional to stress) appears to be slightly higher in welded than in unwelded material.



Figs. 3b and 3c. Results of Stress Tests on Flat Plate Specimens

(*d*) The modulus of elasticity of a small test piece, entirely composed of material of the weld, was about 11,700 tons per square inch as compared with about 13,500 tons for mild steel and about 12,500 tons for wrought iron.

II. Ultimate Strength and Ultimate Elongation

(*a*) The ultimate strength of welded material with small specimens was over 100 per cent of the strength of the unwelded steel plate for thicknesses of ½ in., and averaged 90 per cent for plates of ¾ in. and 1 in. in thickness.

(*b*) Up to the point of fracture, the extensions of the welded specimens are not sensibly different from those of similar unwelded material.

(*c*) At stresses greater than the elastic limit, the welded material is less ductile than mild steel; and the ultimate elongation of a welded specimen when measured on a length of 8 in. only averages about 10 per cent as compared with 25 to 30 per cent for mild steel.

III. Alternating Stresses

(*a*) *Rotating Specimens* (round bar)

(*1*) Unwelded turned bars will withstand a very large number of repetitions of stress (exceeding, say, 5 millions) when the range of stress is not greater than from 10½ tons per square inch tension to 10½ tons per square inch compression.

(*2*) Welded bars similarly tested will fail at about the same number of repetitions when the range of stress exceeds ±6½ tons per square inch.

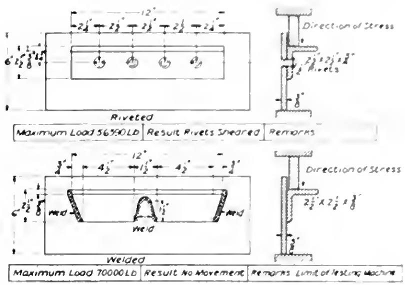
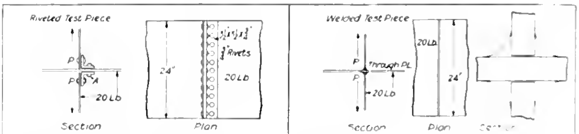


Fig. 4b. Tests to Determine Relative Value of Riveting and Welding for Bracket Connections, etc.



Load Applied Tons	Remarks	Load Applied Tons	Remarks
5 0	No Apparent Movement	50 0	No Movement
10 0	" " "	100 0	" "
15 0	Caulking Opened One Side 15/1000" Other Side 2/1000"	125 0	" "
20 0	" " " " " " "	150.0	" "
30 0	" " " "	170.0	" "
40 0	" " " "	209 0	Broke Through Plate at Holder
49 0	Rivet Points Pulled Through Angle "A"	Limit of Machine	Welding Intact

Fig. 4a. Relative Effectiveness of Riveted and Welded Joints with Regard to Watertightness

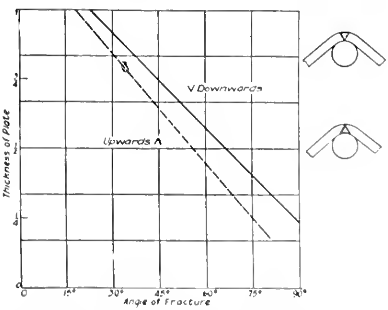


Fig. 3d. Results of Bending Tests on Flat Plate Specimens

(*b*) *Stationary Test Pieces* (flat plate)

(*1*) Butt welded specimens will withstand about 70 per cent of the number of repetitions which can be borne by an unwelded plate.

(*2*) Lap-welded plates can endure over 60 per cent of the number of repetitions necessary to fracture a lap-riveted specimen.

IV. Minor Tests

(*a*) Welded specimens are not capable of being bent (without fracture) over the prescribed radius to more than about 80 degrees with ¼-in. plate, reducing to some 20 degrees where the thickness is 1 in. Unwelded material under the same conditions can be bent through 180 degrees.

(*b*) Welded plates can withstand impact with a considerable degree of success; a ½-in. plate of dimensions already quoted sustained two successive blows of 4 cwt. dropped through 12 feet, giving a deflection of 12 in.

on a length of about 4 ft. 6 in. without any signs of fracture in the weld.

V. Chemical and Microscopic Analysis

(a) *Chemical Analysis*

(*1*) The electrode was practically identical with mild steel, but there was a greater percentage of silicon.

(*2*) The material of the weld after deposition was ascertained to be practically pure iron, the various other contents being carbon 0.03, silicon 0.02, phosphorus 0.02, and manganese 0.04 per cent respectively.

(b) *Microscopic Examination*

(*1*) The material of the weld is practically pure iron.

(*2*) The local effect of heat does not appear largely to affect the surrounding material, the structure not being much disturbed at about $\frac{1}{16}$ of an inch from the edge of the weld. The amount of disturbance is still less in thin plates.

(*3*) The weld bears little evidence, if any, of the occurrence of oxidation.

(*4*) With welds made as for these experiments, i.e., with flat horizontal welding, a sound junction is obtained between the plate and the welding material.

VI. Strength of Welds (Large Specimens)

(a) *Butt Welds*

These have a tensile strength varying from 90 to 95 per cent of the tensile strength of the unwelded plate.

(b) *Lap Welds*

(*1*) With full fillets on both edges, the ultimate strength in tension varies from 70 to 80 per cent of that of the unwelded material.

(*2*) With a full fillet on one edge and a single run of weld on the other edge, the results are very little inferior to those where a full fillet is provided for both edges.

(c) *Riveted Lap Joints*

For plates of about ½-in. thickness, the specimens averaged about 65 to 70 per cent of the strength of the unperforated plate.

Typical examples of the statical strength of large specimens of riveted and welded joints are given in the following Table I.

TREBLE RIVETED LAP JOINTS

Thickness Inches	Dia. of Rivet Inches	Breaking Stress Unperforated Plate Lb. per Sq. In.	Strength of Plain Plate Lb. per Sq. In.	Percentage Strength of Joint
0.49	7/8	42,400	61,400	69.0
0.53	3/4	38,300	54,700	62.5

LAP WELD—FULL FILLET—BOTH EDGES

Thickness Inches	Total Sectional Area Sq. In.	Breaking Stress Lb. per Sq. In.	Strength of Plain Plate Lb. per Sq. In.	Percentage Strength of Joint
0.514	10.02	45,300	63,600	71.0
0.73	8.76	40,330	59,600	68.0

BUTT WELD—NOT STRAPPED

Thickness Inches	Total Sectional Area Sq. In.	Breaking Stress Lb. per Sq. In.	Strength of Plain Plate Lb. per Sq. In.	Percentage Strength of Joint
0.505	10.66	61,000	63,600	96.0
0.76	9.88	54,680	59,600	91.5

Industrial Training in War Time

By E. E. MacNary

Superintendent Training, Emergency Fleet Corporation

When it is considered that our shipyards today employ seven men for each man in their service but one year ago, it will be realized that the training of these thousands of workers in trades somewhat allied to, or entirely foreign to their own, was a Herculean task comparable with the almost miraculous construction of the shipyards themselves. The first phase of this work was the training of 1000 selected veteran workers as instructors to carry out the training of the masses of newly employed workmen. The article below describes the procedure followed and the opening paragraphs give testimony as to the magnificent success achieved. —Editor.

"Our training department made it possible for us to do this job," said the vice president of a large shipbuilding company. "It is the heart of our organization," he continued. His company had put the Emergency Fleet Corporation's plan for training workers to a severe test by building up a large production organization of men knowing nothing of shipbuilding. The 60,000 men employed in our shipyards last fall (1917) have been increased to 400,000 at the present time, and will probably be expanded to nearly 600,000. This means that a large training program has been carried out and will be continued. To accomplish this amount of training in the time available, it has been necessary that the most effective means be utilized for breaking in men to their new trades. The old hit-and-miss methods were not used in war time.

Three groups of men are considered in the emergency training program. First, the men already employed in shipyard trades who will be required to hold more responsible positions as the working force is expanded, to become the leading hands, quartermen, and foremen. Second, the large group of men working in allied or kindred skilled trades who can in a short time be trained to some part of shipbuilding in which they can utilize a portion of their former skill and experience. Third, the group who have had no skill or experience that will assist them in learning shipbuilding trades.

"Who is going to do this training?" was asked when the problem was first presented. The only men that can teach a trade are those who thoroughly know that trade and have had long experience in it. In the war emergency, however, training is operated under forced draft and a 100 per cent job is required. There can be no guesswork, the number of men must be trained when they are wanted, and they must be able to do the new job up to standard requirements. This means that these skilled workers who are to give the training must be skilled instructors as well. That is, they are required to know not only how to do the job, but also just how to put their knowledge over to others in the most effective way. Rarely, however, is the skilled worker a skilled instructor as well.

Here was the rub. Skilled men who know shipbuilding trades could be found in that original 60,000, but how could they be expected to be skilled instructors as well? "Give them an intensive course in instructor training," was the answer to this question; and that is what the Emergency Fleet Corporation, in co-operation with the ship-

Fig. 1. Group at Work in Classroom

yards, has done. The shipyards were asked to select skilled workers with not less than five years' experience from the trades that required men to be trained. These men were given a six weeks' intensive course in how to put their trade knowledge over to others.

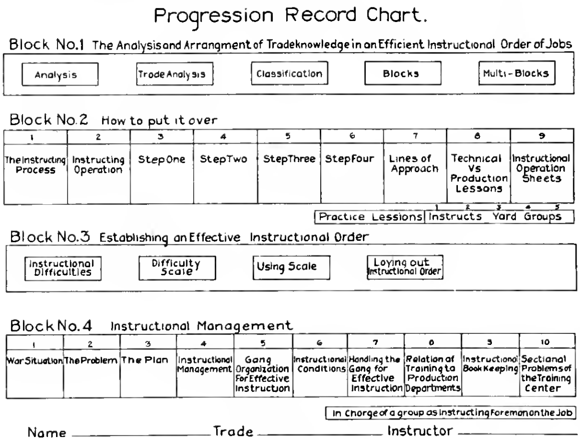


Fig. 2. Progress Record Chart

An outline of the instructor training course given to the skilled shipyard workers is shown in Fig. 2. The prospective shipyard instructor is first asked to analyze his trade, placing the jobs and operations in the production order. He then is taught how to put his instruction over; that is, he learns what a good lesson is, the kinds of lessons needed under varying conditions, and how to give them most effectively. By this time the prospective instructor appreciates the fact that the production order of his trade analysis is not suitable for instruction purposes, but that he must revise it by arrangement into an instruction order so that the learner of the trade starts with the simpler operations, and makes gradual progress to the difficult operations. The last phase of instructor training gives both instruction and practice in managing groups of learners who are being trained in the yard or shops. The shipyard itself is the only suitable place for giving this instructor training, in order that the work may be checked up with actual shipyard conditions, and where the prospective instructor may at the time put in practice the instruction methods given him.

At the completion of the instructor training, the men in the course set up trade training for learners in the yards and shops. Over one thousand skilled shipyard workers have been trained as instructors. Eighteen different trades are represented in this group. Training these men to become instructors, of course, is but the beginning of the job of establishing training in industrial plants. The real task is the organizing and operating of training departments of sufficient capacity and effectiveness to meet the requirements of the industry.

An educational engineer is required in the setting up of an efficient economical and successful training department, just as an electrical engineer is required for the designing of an electrical power plant. There are factors of efficiency in training as there are in the operation of electrical equipment. As the electrical engineer deals with principles and physical laws controlling the generation, distribution, and application of electrical power, so the educational engineer deals with principles and laws controlling methods of instruction, organization of departments that will co-ordinate with production without friction or interference, and the proper application of training processes.

In planning the emergency training for shipyards, the Emergency Fleet Corporation took into account the following factors:

(1) The application of the training.
  (a) On actual production.
  (b) Under regular working conditions.
(2) The order of instruction.
(3) Number of men to an instructor.
(4) Skill of instructor.
(5) The organization that gives training.

In order that training may be efficient, it must be given on the same processes that are involved in regular production. When a learner is doing a real job and is given to understand that it must meet the standard requirements of production, there is a strong incentive on the part of the learner to do the job in a thoroughly satisfactory manner. Practice work or exercise work does not give the same incentive. Training on practice work or exercise work requires the learner to relearn certain steps and processes when he is put on regular production. Because of the lack of incentive and because of the necessity for readjustment to new conditions, training on exercise work or practice work is wasteful in space, time, and material. In the case of training riveters, for instance, learners are started in actually driving "snap" on button head rivets on work that is not required to be watertight, on simple work that is done on the ground, such as riveting clips, brackets, etc. Under a competent riveting instructor, three or four gangs can do this work entirely satisfactorily. As rapidly as each gang is able to progress they are put through experience in riveting work that is increasingly difficult, as bulk heads and decks, and finally on bottom shell riveting.

This work is not done in a school, but under regular working conditions. The learner of riveting learns to rivet in the same places in which the regular riveters work, on the ground and on the ship. He does not have to readjust himself from school conditions to working conditions, but is continually becoming accustomed to the situation he must work under. This is true of all the hull construction trades, as shipfitting, drilling and reaming, chipping and caulking, and shipwright work.

The order of instruction has a great deal to do with the speed and ease with which the learner acquires ability to do a skilled job. Starting with too difficult a job is like an excessive starting torque in an electric motor. Crowding difficult steps too rapidly, one after the other, or introducing difficult operations in an improper order, is similar to overloading a motor, causing heating up and possibly burning out. The learner becomes very often discouraged, loses confidence, and in some cases quits the job if his progression through difficult operations is not properly arranged. A reasonable loading of difficulties

Fig. 3. Training Gang in Bolting

Fig. 4. Training Gang in Chipping and Caulking

with as rapid acceleration as can [illegible] put up to the learner is desired. In order to do this the skilled instructor applies what is known as a "difficulty scale" [illegible] jobs in hand in order to determine the order in which they should be given to the various learners. This difficulty scale is drawn up by the trained instructor when he revises his production analysis of his trade into an instruction analysis. This difficulty scale takes into account the various difficulty factors in the trade, arranging "accuracy difficulties" from the very coarse to extremely accurate, "finish difficulties" from rough to fine, "complexity of operation difficulties" from simple to complex, "skill difficulties" from machine guided operations to highly skilled hand operations. By gauging the operations in hand with this difficulty scale it can readily be determined by the instructor what jobs should next be given to the various learners so that their progression is regular and involves the greatest acceleration possible without discouraging or confusing the learner.

The number of men to an instructor is a vital factor in efficiency. Where it has been attempted to reduce the cost of instruction by increasing the number of men to an instructor, it has frequently been found to be true that the cost of training really has been increased, owing to the fact that the instruction has become less efficient and has taken a much longer time than if fewer learners were instructed at one time. The number of learners an instructor can most efficiently handle varies with the trade, the working conditions, the ability of the instructor, and the ability of the learners. An electric welding instructor can handle effectively 6 to 8 learners at one time, a machine shop instructor 12 to 15, a bolting-up instructor 16 to 20. If these numbers are doubled, the length of time for completing the training is usually more than doubled, so that no gain in time or in cost is secured by overloading the instructors.

The skill of the instructor has considerable bearing on the effectiveness of the training work. An instructor who understands the difference between telling and teaching, or showing and teaching, and can employ effective teaching methods, can turn out more trained men in a shorter time than the instructor who cannot employ successful teaching methods. A skilled instructor can put himself in the place of the learner, can get him to think of the things he wants him to think of, and successfully put over the new ideas employing the many teaching "tricks" to be sure the lessons "take;" he can gauge the ability of the learner to receive the next more difficult steps, can keep the learner right up on his toes, can co-operate with the production department in helping them meet their needs without friction and without demanding too much attention. This is the type of man that has helped to win the war through emergency training, and has made his work count as much as the man behind the gun.

In the yards where these trained instructors are working, the managements are unanimous in their praise of the results secured in the training of learners. Several large yards emphatically state they could not have built their ships without these skilled instructors. Others state the results to be remarkable and wonderful.

In order that the skilled instructors in an industrial plant may be most effective on their job, it is necessary that a training organization be established. If a number of instructors are employed, a training director is required, who will be responsible solely for the instruction work. A training director should be fully acquainted with instruction methods and the problems involved. The instructors on his staff are responsible to him for the effectiveness of their instruction. His duties include the supervision of the instruction work, the negotiations with the production foreman for the securing of adequate production work for the learners, the determination of just how the production department requires the work to be turned out, and the smoothing out any difficulties that might arise between the instructors and the production department. Usually a skilled shipyard man with executive ability who has been through the instructor training has made the most successful director, although there are some notable exceptions where a good administrator, though not a shipyard man, has studied the course and made a very satisfactory director of training. If the department is a large one, both the training department and the production department require co-ordinators; the training co-ordinator responsible for knowing what production work is needed for training the various groups of learners, and the production co-ordinator representing the production department and responsible for knowing where the required production work is located and arranging with the respective foremen for assignment of what work is needed for training.

This type of organization obviates the necessity of instructors losing time, and also reduces unnecessary friction that may arise from the instructors individually going to the production department to secure the various jobs they need. The director of training usually heads up to the general manager or his representative in charge of the production department. The training department is recognized as a distinct department in the plant. If no organization is established and the instructors are placed under various foremen in the plant, as has occurred in two or three instances, with no one looking after the effectiveness of the instruction itself, the instructors soon become sub-foremen of production. In fact, without a training organization, the training work is soon absorbed entirely in the production department. With a proper organization, the training work can be maintained at a high point of efficiency, difficulties with the production department can be avoided, and learners can be trained without holding back the production schedule or interfering with the production program in any way. The foremen who previously had two responsibilities—getting out production and breaking in men—are relieved of this second responsibility and can devote their entire thought and energy to production, the training department assuming all responsibility for the training of men. With a well-organized training department an industrial plant can know the output of trained men, the cost of training, the amount of production turned out during training, and the quality of this production. Learners in an efficient training department will produce, while under instruction, as a general average, 20 to 25 per cent less than a similar number of workers in a regular production department.

The employment department and the training department work in close co-ordination. The function of the training department in relation to employment is that of supplying skill to workers when the employment department is unable to secure workers with necessary skill in the market. Theoretically, the employment department hires the workers, and the training department on requisition trains the workers and turns them back to the employment department for placement in the plant.

The results attained by well organized training departments more than prove the value of systematic, organized training as compared to the old hit-and-miss methods. Shipyards operating these departments are continually reporting the success of the training work, claiming that they would be unable to carry out their program without such an organization. The length of time for breaking in workers has been considerably reduced, while the quality of the work turned out by learners has been greatly improved. At the present time training has been introduced in all of the shipbuilding districts in the country, including the Atlantic coast, Gulf, Great Lakes, and the Pacific coast sections. The 1,000 instructors have been trained in 34 different centers. These men represent 71 yards. Each man has a capacity for training about 150 learners per year. While this system has been applied to shipyards, the plan was developed from experience in training for manufacturing plants, and of course is equally applicable to any industrial plant requiring the breaking in of a large number of workers.

The Training of Electric Welders

By H. A. Horner

Head of Electric Welding Branch, Education and Training Section, United States Shipping Board, Emergency Fleet Corporation

The preceding article covers in a general way the teaching of some eighteen different trades practiced in shipbuilding. The following article is confined to a comprehensive description of that part of the training activities designed for electric welders; and it is a significant fact that while the welder must be a skilled workman so also must be the riveter, plumber, forger, etc. In the electric welding course the salient factors are the materials to be welded, the electrode, the operator, and the instructor; and it is under these headings that Mr. Horner describes the work of the training organization.—Editor.

There are four essential points to be considered in the training of electric welders:

(a) materials to be welded,
(b) the electrode,
(c) the operator,
(d) the instructor.

Materials

As to the materials to be welded, it is obvious that as far as the welding operator is concerned he has a limitless field of possibility for the exercise of his mental ingenuity as well as his skill of manipulation. It is because of these possibilities that in the Emergency Fleet Corporation schools, or *training centers*, every endeavor is made to give the learner the benefits of not only universal practice but of universal information. Many of the questions connected with the weldability of certain materials must, at least for the present, be left to the investigation of the scientist, though, as in other fields, the operator has succeeded in obtaining good electric welding through his own practical methods. The results of such practical work have not been consistent, and for this reason the ablest metallurgists are striving to reach their conclusions by the comparative method, namely, placing side by side for investigation both the good and the poor results. Such questions as the weldability of cast iron, of high tensile steel, of alloys of steel, are illustrations of the metallurgical work that is now in progress.

Concerning these matters the welding operator need only have at hand the general points of progress, so that he will be properly guided in his every-day work to avoid certain jobs that by error may be placed before him. The purpose for the training of welders set down by the Emergency Fleet Corporation practically settles the question of materials for their specific training, as the application of this process is for the building of steel ships. The steel mills of this country are furnishing a fairly uniform standardized structural steel for use in the shipbuilding program, and it is with this material that the various training centers are provided. The men under training are skilled in welding all sizes of steel plates and shapes that are employed in the present design of the ships under construction. Provision is made at each one of the centers not only for the early practice work on small samples, but progressive exercises are arranged so that the operator by gradations arrives at practice work on heavy materials with long continuous seams. Further, he applies to these increasingly difficult exercises the use of the electrode in all the various positions.

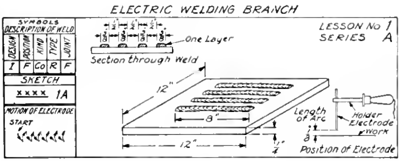
Electrodes

As to the electrode there is also a great deal of scientific work to be done. It can hardly be said that the ideal electrode, or even a universal electrode, has yet been discovered. The interest surrounding the possibilities of different chemical compositions in the electrode is perhaps one of the most fascinating problems of the metallurgist; especially, when it is realized that there are many variant conditions that change the results of the weld without affecting the original composition of the electrodes. It is for this reason that the practitioner will experiment with coated, dipped, and covered electrodes, and then revert to the bare electrode in the endeavor to prove that similar results can be obtained with it as well as by any of the various physical modifications.

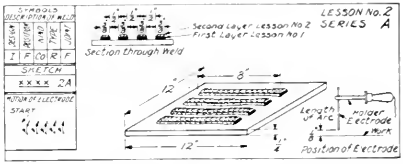
Again such considerations are beyond the necessities of the trained welder and it is only requisite for him to follow the general trend of improvements in this tool, just as any other craftsman will see to it that his tools are of the proper temper and of the correct dimensions, etc. It is necessary, as in the case of all manufacturing work, that the designer in preparing his designs to be carried out by the welder should carefully study both the materials to be welded and the electrode material to be used by his skilled craftsman.

Operators

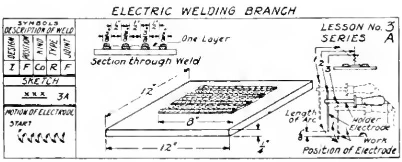
The electric welder has just as important a duty as regards the electrode as has the designer in its selection. It is the function of the welder to properly manipulate the electrode, no matter what its quality, composition, or structure. It is necessary that work may be set up before the operator He, therefore, has to practice so as to accommodate his right arm muscles not only to action in a flat, horizontal, vertical, or overhead position, but for skillful manipulation in all these positions. Besides this, and while he is so operating, he must skillfully adapt the angular position of the electrode and the work so as to be able to draw up to the surface of the V, or the top layer of the weld, all slag or foreign substances that may affect the results. It can be seen from this that it is a conservative estimate



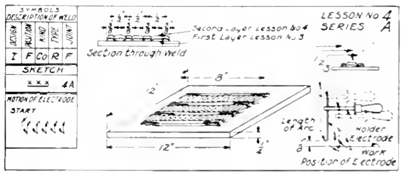
Lay one layer of 8 in. of welding 3/8 in. wide with 8 in. of electrode in one row. Four such rows to be made with ½-in. space between rows.



Lay a second layer of welding 8 in. long by 3/8 in. wide with 8 in. of electrode on each of the four rows which were made in lesson No. 1. Absolute unity must be accomplisbed between the first and second layers.



Lay welding metal 8 in. long with 12 in. of electrode in one layer in each ½-in. space between welds made in lesson No. 2.



Lay a second layer of welding material 8 in. long in each ½-in. space between the four rows made in lesson No. 2. The welding material to be flush with adjoining metal and all welding metals to be in perfect unity upon completion.

Fig. 1. Progressive Exercises in Arc Welding. The electrode holder can be held in any convenient position to the work but the electrode at all times must be at right angles to the work. If necessary to obtain a comfortable position the electrode wire may be bent to bring it at right angles to the work. Maintain an arc 1/8 in. long.

he become skillful in the movement of the electrode in every position in which his work is set up for him. The "goodness" of the weld he makes is the direct result of providing sufficient heat at the fusion point of the parent metal as well as maintaining a uniform flow of heated electrode material in the filled-in portions of the weld. It is because of this point that emphasis must be placed upon the conscientiousness of the operator, as it is the consensus of opinion that certain men will never become electric welders. The semi-circular swinging movements between the beveled edges of a steel plate have their variations for every position in which this to say that the personal equation of the operator is 90 per cent of a good weld.

Instructors

What character of men should be selected for the training of electric welders? And what should constitute their fitness for important production work when they have been made proficient in the use of the electrode? The system now in force by the Emergency Fleet Corporation is in the form of an invitation to the steel shipbuilder to send their own men to the electric training centers. These men are selected by their employers and the instructors are expected

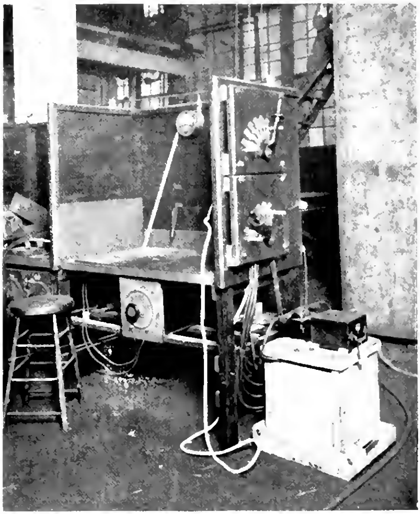


Fig. 2. Alternating-current Welding Transformer

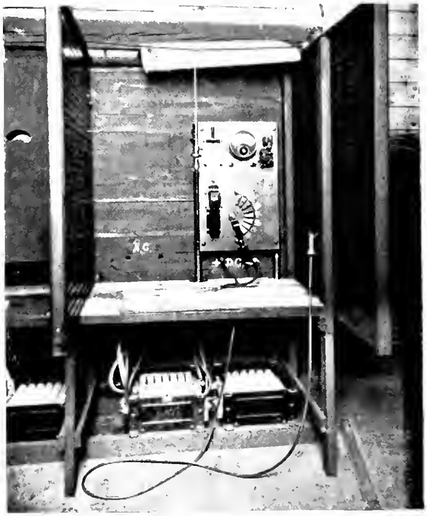


Fig. 3. Direct-current Resistance Welding Equipment

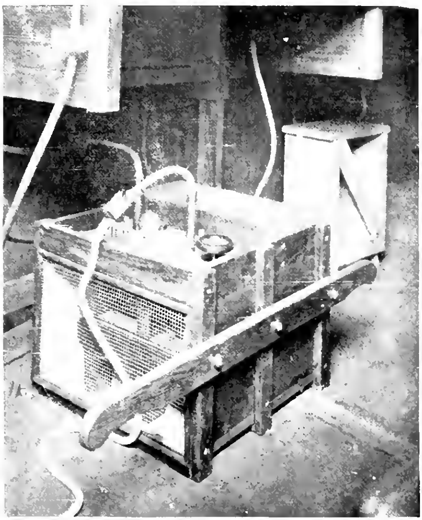


Fig. 4. Alternating-current Welding Transformer

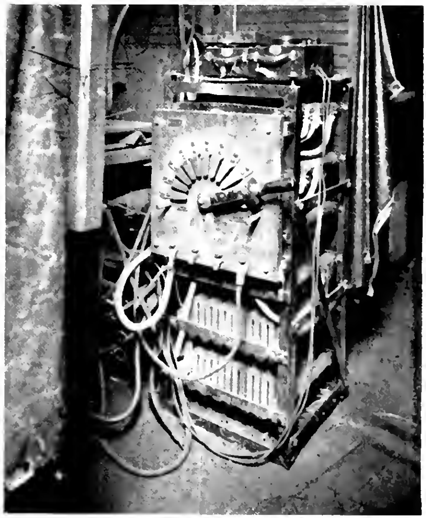


Fig. 5. Direct-current or Alternating-current Resistance Welding Equipment

Booths and Various Types of Welding Equipment in use at the Emergency Fleet Corporation Welding School at Schenectady, N. Y.

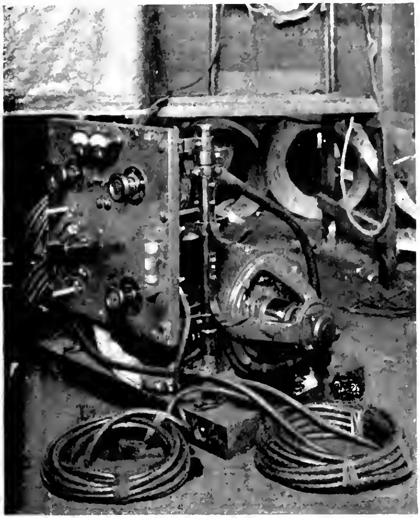


Fig. 6. Direct-current Portable Balancer Equipment

Fig. 7. Alternating-current Reactor Welding Equipment

Fig. 8. Proper Distance at which to Hold the Electrode from the Work

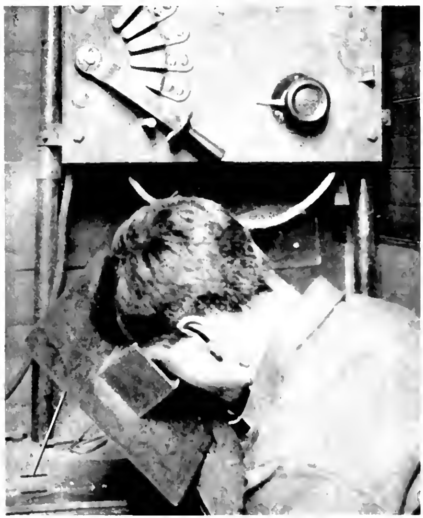


Fig. 9 Improper Distance at which to Hold the Electrode from the Work

Booths and Various Types of Welding Equipment in use at the Emergency Fleet Corporation Welding School at Schenectady, N. Y.

to take this presumably raw material and convert it into production value. There are many essential characteristics which a man who hopes to be successful in this particular line of endeavor should possess. Perhaps the most important characteristic is that of firm purpose and a disregard of fallacies of which he has been previously conversant or latterly been made acquainted with. It goes without saying that the man must be conscientious and a believer in maintaining a sensible view of the attainment of perfection in his work. He must be of sober, earnest, and temperate habits, all of which naturally subscribe to a steady and firm handling of the electrode. It will at once appear that such a selection, or the attributes of such qualities, would make it difficult to provide men for such work, and careless thinkers in this way have made erroneous deductions as to the possibility of obtaining sufficient electric welders for accomplishing results in the hastening of the construction of the standard steel ships now building. It is a mistake to assume that men cannot be found with such characteristics. Undoubtedly it requires an aptitude upon the part of those responsible for the selection, in exactly the same way that we find the success of great business organizers in their selection of men for large and responsible executive positions. It is found in the short period since the beginning of the electric welding training that the nature of the work itself reacts to a large extent upon the character of the man, exactly in the same manner that the art itself of welding flashes upon the mind of the man himself after several weeks of practice. It has been noted in certain men under training that characteristics such as are desirable for him in this art, and were unknown to himself and to his associates before, are most pronounced upon the conclusion of his course of instruction. Needless to say, conversely detrimental characteristics are also obvious in certain cases, and it then becomes necessary for those in charge to exercise their judgment in a prohibition against the further exercise of such men in the use of the electrode.

This would seem to throw the onus of a good electric welder very much upon the man who instructs him. In view of the fact that the subject of industrial training has much to do with the question of the training of instructors, and as this subject is being treated in an admirable manner in an article by E. E. MacNary, Superintendent of Training Emergency Fleet Corporation, it is expedient that the thoughts expressed should be only those concerned with the experience of instructors specifically prepared for the training of electric welders. The process, the methods used, even the methods themselves, are simple. The mental attitude of the man to be trained is invariably in opposition to the instructor. It becomes necessary, therefore, for the instructor to impress an immediate interest into the mind of the student so that he converts this opposition into a definite enthusiasm for the attainment of perfect results. He has to do more. At times the student becomes tired at the monotony of the exercises placed before him. These exercises must by their very nature be repetitive. This necessitates the use of the discriminatory faculties of the instructor in order to release a man from over-practice in one line and so diversify his work as to accomplish the desired results without an enforced monotony. The clever instructor not only studies the material work of his student and carefully watches his mental attitude but also those characteristics specified for the good craftsman. In some cases the instructor has discovered naturally bad habits, and before the man has completed his course has entirely regenerated him.

The procedure of the Emergency Fleet Corporation following the proficiency of the student in the use of the electrode is to further permit the man to attend a course of about five weeks of intensive study of the applicable principles of pedagogics. This course is one designed entirely for the practical every-day man. Many cases have come to the attention of those following this work, where the practical man has himself wondered at his own ability to impart his knowledge quickly and satisfactorily to a fellow worker. By means of this course of instructor training the employee of the shipyard is now fitted to return to the plant and instruct other men in the art of electric welding. In this manner the steel shipbuilder quickly provides for himself a nucleus of electric welding craftsmen.

Practice Exercises

There are included several sample lessons for the students in electric welding centers of the Emergency Fleet Corporation. These lessons, or practice sheets, have been prepared by W. C. Schrader and are to be used for the purpose of uniformity as well as to expedite the early steps in the training process. These exercises, it will be noted, require the student to send his work to headquarters as a record of his performances from the inception until the completion of his course. It is expected that by making the ties between the student and those in responsible charge a little closer, there will result a keener appreciation of the final certification of the student. In this regard it must be stated that the Emergency Fleet Corporation intends to certificate every man who has been trained under its auspices and whose standard of production work warrants this estimation.

Training Centers

Three training centers have been established, viz., one at the works of the General Electric Company in Schenectady, N. Y.; one at the works of the Quasi-Arc Weltrode Company, Brooklyn, N. Y.; and the third at the works of the Lincoln Electric Company, Cleveland, Ohio. The Schenectady center was the first one established, and it is owing to the energy and patriotism of the General Electric officials that this training center was put into operation in such rapid time, and that it so quickly obtained and maintained a reputation for the proficiency of the men that have been turned out for the shipbuilder. Within a few weeks another training center will be established in Philadelphia, and at about the same time it is expected that a training center at San Francisco, California, will be active. This latter will be the first training center on the Pacific slope, and doubtless will soon be followed by others. Training centers will be provided as the demands of the shipbuilders increase.

A Review of Electric Arc Welding

By John A. Seede

Power and Mining Engineering Department, General Electric Company

In these days when the development of the art of electric welding is progressing at a phenomenal rate, a review of the subject is of interest. Mr. Seede outlines below the evolution of the present practice of arc welding, starting at the time the weld material was deposited by being fed into a long arc drawn by a carbon electrode. He then traces the progression of the art to its present day status, and gives especial consideration to the subjects of carbon electrode welding, metallic electrode welding, electrodes, fluxes, holders, alternating-current arc welding, automatic welding, and the apparatus employed.—Editor.

When one speaks of welding, the picture brought to mind is that of a flaming forge and powerful men hammering metal to the accompaniment of considerable noise and flame, and for certain classes of work this process will never be superseded. It is well known that the blacksmiths' welds require good metal and careful workmanship, and the same conditions are required in the newer development of arc welding, which does not supplant but rather supplements the ancient forge.

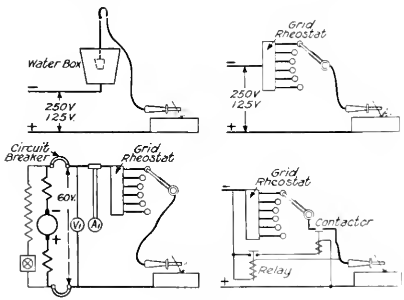


Fig. 1. Arc Welding Circuits as First Used

As far as the qualities of the two welds are concerned, the blacksmiths' weld is undoubtedly superior; but a large amount of the superiority is due to the working of the metal during and after the weld has been made. If the arc weld can be heated and worked it will give results equal to the forge weld, because we change the cast structure of the weld into the wrought character, as when welding forgings, etc.

Because of the additional interest centered on it during the last year or two, considerable data have been obtained that throw light on phenomena that have been obscure, and also indicate many problems, especially from the physical and metallurgical standpoints, that remain to be cleared up.

Carbon Electrode Welding

As originally practiced arc welding was a rather crude process, consisting of drawing an arc about an inch long from a carbon electrode to the work, and feeding the welding metal in the form of a welding rod, similar to the ordinary soldering process.

In the ordinary case this is not difficult, but in deep holes it was sometimes necessary to add the metal in small plugs and fuse it to the work, thus practically making a steel

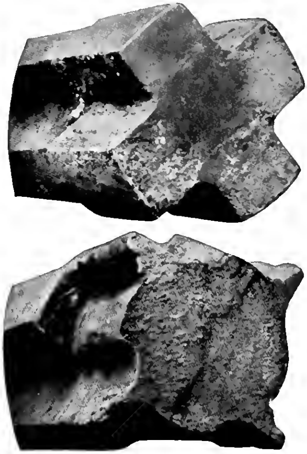


Fig. 2. Worn Steel Roll Wobbler Repaired by Carbon Arc Welding

casting. A graphite or hard carbon electrode usually about $\frac{1}{2}$ in. or $\frac{3}{4}$ in. diameter sharpened to a $\frac{1}{4}$-in. point was used for the average work, requiring 250 to 450 amperes. Lighter and heavier electrodes were used, depending on requirements, such as very light material taking 50 to 200 amperes and very heavy welding and cutting taking current values up to 1500 amperes.

On account of the variable regulation of shop circuits, uncertain quality of electrodes and poor composition of welding material, together with indifference of operators, arc welding was more or less justly regarded as something to be avoided where reliability was concerned; its principal work being very rough.

As time went on several investigators discovered the possibilities of the process, that is, that good welds could be made and consistent results obtained by insisting that the operator maintain an arc of medium length, not so long that the metal would oxidize or so short that it would harden from being filled with carbon; then arc welding began to be used in places that required a reliable product. In this stage of the development the process was mainly used in what might be called secondary production, that is, in filling blowholes and other defects in castings and forgings, building up metal that was removed through errors in workmanship, removing broken taps from all kinds of work, etc.

Metallic Electrode Welding

Later, instead of drawing an arc from a carbon electrode and feeding the metal in the form of a separate rod, better results were obtained by drawing the arc from the welding metal, doing away with the carbon electrode. It was soon found that the new process was considerably more difficult than the old one, as the arc was considerably shorter, having approximately one half the voltage drop, and therefore more sensitive and more difficult to maintain so as to produce good results.

Fig. 3. Locomotive Side Frame with Defective Frame Cut and Welded

Almost immediately the new development was handicapped and the general situation confused by competitive claims on composition of electrodes, use of fluxes, polarity of electrodes, electrode holders, control equipment, and other factors of more or less importance.

Despite these conflicting factors steady progress was made, and metallic electrode welding soon began to be used for such important work as repairs on boilers of locomotives, tugs and other vessels, and for many other applications requiring comparatively high tensile strength with some ductility.

An immediate benefit of the new process was welding in a vertical plane, and the process was soon carried to overhead welding, which is sometimes necessary but should be avoided wherever possible as it is a severe strain even on the best operators. Both of these developments were of prime importance, the first on account of insuring a better weld, and jointly on account of being able to make welds that were previously impossible.

Vertical and overhead welding permit of many repairs being made on complicated machines without taking them out of service, and this is of the first importance when we consider such applications as locomotive repairs, etc.

It is believed by many that the best way to do welding is to have the work horizontal and to make conditions as easy as possible for the operator; but while this may be permissible for the best operators, or in carbon arc work, generally it makes the covering of defective work easier and therefore is not desirable for the average man.

Arc-welding methods must necessarily be a compromise between easy methods to keep up production and difficult methods that insure good welds but are harder on the operator. As it is difficult to differentiate between good and bad welds, the leaning should be toward the method that insures good welds.

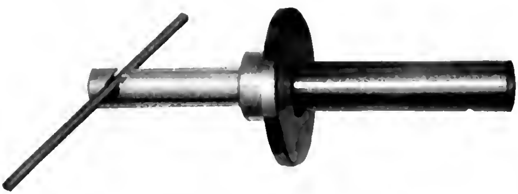


Fig. 4. Electrode Holders for Arc Welding

The importance of metallic electrode welding in shipbuilding is being demonstrated very rapidly, and it is permitted in many places where the strains are in compression or bending. This is permissible, as shown by bending tests well over 60 deg. which demonstrate reliability in ordinary compression and bending strains, and possibly under live loads.

Electrodes

Ordinary mild steel rods, being most easily available, were probably used in the first

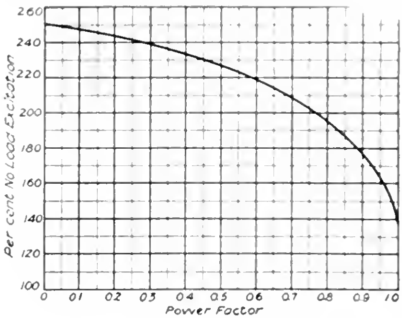


Fig. 5. Curve Showing Effect of Low Power Factor Load on Generator Excitation

carbon electrode welding and practically the same material, with perhaps less carbon, and consequently higher melting point, is now used not only for bare electrodes but as the core in covered electrodes.

When the metal passes through the arc some of the constituents are partly burned out, mainly manganese and carbon, and to obtain any given composition in the weld due allowance must be made for such losses and the electrode metal made accordingly.

The question of alloy materials and their effect on welds is undergoing careful investigation and important results are anticipated in the near future.

Fluxes

The question of fluxes has been the source of considerable contention. The early metallic electrode used a mixture of pulverized carbon and borax together with other materials of more or less imaginary benefit, while the present flux-covered electrodes contain various additional elements to assist in producing high-class welds. Undoubtedly such coatings have beneficial effects under certain conditions, but it is thought considerably more data must be obtained before we are finally able to state whether they should be used generally.

Holders

Holders have been developed so that we now have a light, simple, easily operated, balanced device which is nothing more nor less than a simple clamp designed to avoid overheating and to protect the operator's hand. In this connection we may refer to magnetic appliances which have been introduced at various times; and while disregarding all claims affecting the magnetic projection of molten metal into the weld, it is entirely possible that there may be advantages in closely surrounding the arc stream by a magnetic field directed according to conditions, and a simple means will undoubtedly be found for doing this if it is found desirable.

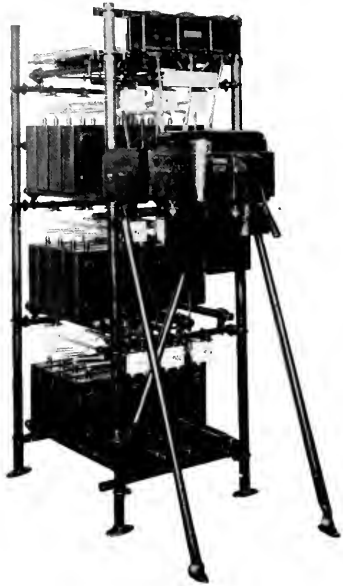


Fig. 6. Static Condenser

Masks

Any auxiliary device that affects the ability and comfort of the operator more than the mask is difficult to find, and his output is affected accordingly. These masks vary from the hand shields, that afford a minimum of protection but are easily handled, to the somewhat cumbersome head shields that protect the entire head, front, and rear, and are inconvenient to remove when starting or inspecting the weld. Considerable study has been made of the shielding qualities of the glass, and this problem is still being carefully investigated.

Alternating-current Arc Welding

After the direct-current equipments had been perfected the question arose as to what could be done with alternating current. The matter was followed persistently, and several equipments were put on the market with which metal electrode welding could be done.

If we look at the matter from the point of heat generation, it is obvious that an equal amount of heat will be developed at the work and at the electrode with alternating-current welding, while with direct-current welding we have considerably more heat developed at the positive terminal. Also in arc welding the negative electrode determines the character of the arc, which permits of making additions to the weld in a way that is not possible with alternating current. Inasmuch as the work always has considerably greater heat-absorbing capacity than the electrode, it would seem only reasonable that the direct-current arc is inherently better suited for this work. For this reason the difficulty of welding with the alternating-current equipment affects the speed of the operation, amounting to approximately 25 per cent.

The direct-current arc furthermore permits the use of bare wire in a much greater degree than alternating-current welding, and this is undoubtedly a factor in its favor during these times when the steel producers are taxed to the utmost, as covered wire requires considerably greater manufacturing facilities than the bare wire. The use of a flux-covered wire that leaves a

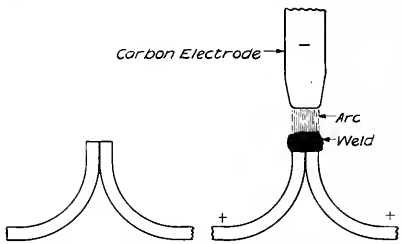


Fig. 7. Sketch showing Method Employed in Joining the Edges of Metal Sheets

solidified coating on the weld also tends to reduce the speed of production and increase the cost of the welding operation, as every particle of the fused slag must be removed before the next layer is put on if proper attention is paid to the quality of the weld.

It is well known that the chief limitation of alternating-current generators is the design and construction of the rotating field. Without going into the question of unbalanced load, it is interesting to note the effect on the field of low power-factor loads such as are obtained from arc welding. As will be seen from Fig. 5 the excitation of an average standard generator is 195 per cent of no-load excitation at 80 per cent power-factor, while at 20 per cent power-factor the excitation has increased to 245 per cent, an increase in field heating of 60 per cent. Furthermore, the fixed charges, such as labor, interest, and standby losses, are four times as great with the 20 per cent power-factor load as with the 80 per cent power-factor load.

Such matters should be borne in mind in these times when our power stations are working to their limits in capacity, and essential industries are not allowed to expand on account of power shortage. Each kv-a. of capacity tied up in this way is lost to the

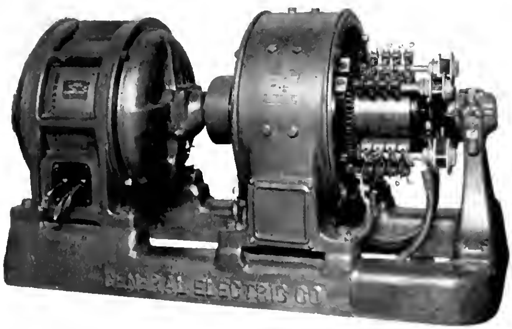


Fig. 8. Standard Constant Potential Arc Welding Set

general power supply, and in view of the satisfactory results obtained from the comparatively recent production of a reliable static condenser, there is no good reason why these harmful effects should be permitted. Suitable relays can be installed to introduce the condensers as required.

Automatic Welding

The desirability of a successful automatic arc-welding device is so great as to warrant special effort in development, and encouraging progress is reported although the difficulties at first appeared insurmountable. In those

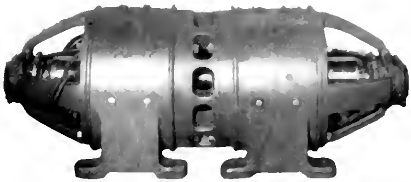


Fig. 9. Single Operator Self-regulating Arc Welding Set

applications where it can be used considerably several advantages result, such as better and more consistent welds through more uniform penetration and even deposit, absence of defects, greatly increased output as the wire can be fed from a reel, and improved load factor. The steadiness of operation permits the use of heavier wire and higher power, so that further increase of added metal may be obtained.

Apparatus

Contemporaneously with this development, the questions of supply and control were studied, and it soon became apparent that the same results could be obtained with considerably greater efficiency and better electrical characteristics generally. The original equipments took power from 125-volt or 250-volt, direct-current circuits, and for certain street railway welding standard voltages up to 550 600 volts have been used, the extra voltage having been consumed in suitable rheostats either of the grid or liquid types. On a 125-volt circuit, which is the commonest standard circuit, with an approximate carbon arc voltage of 50, there would be consumed 75 volts in the rheostats, giving an over-all efficiency of about 40 per cent.

The new apparatus was designed with special consideration to the following points:

The voltage should be as low as possible in order to save energy when using metal electrodes, and yet sufficiently high to strike instantly through scale, oil, and other coatings; and also to permit of a small resistance

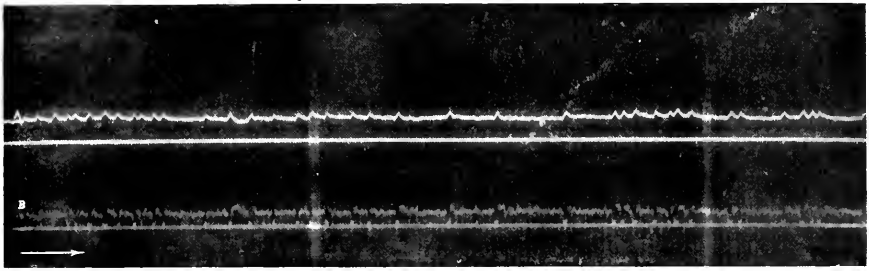


Fig. 11. Constant Energy Arc Welding Equipment

voltage drop to give stability to the carbon arc. Sixty volts was chosen for capacities up to 600 amperes, and in larger equipments 75 volts was adopted as giving better regulation with the comparatively long leads in use where such large capacities are used.

We therefore have an independent circuit which is supplied by a generator designed to give constant voltage at all loads, thus removing one of the causes of poor welds. A higher electrical efficiency also results, which will reduce the power cost. Such an equipment is the best all-around arrangement yet devised, as a 400-ampere outfit can be used for a large amount of carbon arc work, besides permitting two or three operators to work with metallic electrodes when desired. With constant voltage and a series rheostat we have an equipment that is favored by many good operators, as we have a *straight* line characteristic from open circuit to short circuit.

The only difference between such an equipment and a recent self-regulating machine is that the straight line characteristic is approximated by the use of suitably designed field windings, in this way increasing the efficiency. However, such a machine is suitable for only single operator work and can not be used for carbon welding or cutting.

One of the main advantages of the single operator equipment is that the operator has control of both voltage and current, and this leaves him absolutely no chance to duck responsibility by blaming poor results on the electrical equipment; and defective welding can only result from poor metal, incorrect operation, or ignorance in arranging work.

Future Developments

It is doubtful whether there is any ordinary device that is returning as high a dividend on the investment as an arc-welding equipment. Many cases are known where a single operation repaid the original investment many times and with increasing knowledge of its possibilities the return is accordingly multiplied. Without fear of contradiction we may prophesy an ever-expanding field, and with the tremendous amount of work that is being done in experimental investigation, undoubtedly considerable valuable data will be obtained in the near future which will greatly further the applications of arc welding.

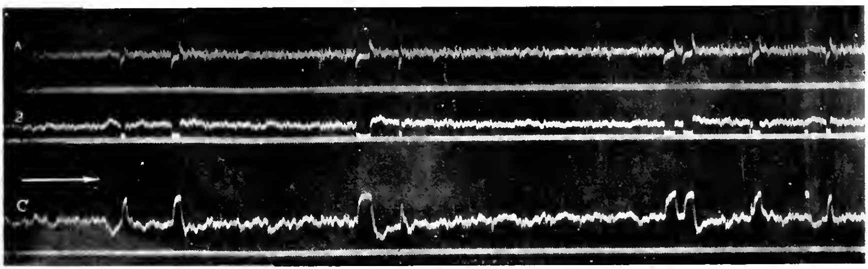


Fig. 10. Constant Potential System with Fixed Series Resistor

Arc Welding in Railroad Shops

By B. C. Tracy

Power and Mining Engineering Department, General Electric Company

The author describes some of the more important applications of the electric weld in railroad [illegible] repairs. Results shown would indicate that in the near future the subject must be given serious consideration by the railroads, not only from an economic viewpoint, but also with the object of increasing our transportation facilities, while new equipment is being built.—Editor.

One of the greatest problems confronting the railroad administration is to increase the supply of locomotives for domestic roads, the American Expeditionary Forces, and the Allies. Requirements for new engines are far beyond the theoretical capacity of the country's plants, and even more so beyond the present rate of production.

Plans for increasing the capacity of the locomotive plants have been under consideration for some time. While these plans have not been abandoned, the work of the administration and of the locomotive manufacturing industry has recently been turned more towards getting all possible output from existing equipment. The principal hindrance is shortage of labor.

Another and important consideration is that of repair plants. If the repair plants are employed fully and systematically, new engine requirements will be substantially reduced, and it may possibly become unnecessary to increase building capacity. All the railroads are equipped with repair shops, fitted to perform more or less important repairs. At present nearly 15 per cent of all the locomotives owned by American roads are now undergoing or awaiting repairs. In other words, of the 63,000 engines on the railroads only about 54,000 are actually in service. If the performance of repairs can be systematized to reduce to a minimum the number of engines out of order, it would mean a substantial increase in the number of engines in service, with a constant reduction of domestic needs for new motive power, thus releasing new power for shipment to our troops or the Allies.

In accomplishing the great variety of repairs common to locomotives, the electric arc welding process has proved to be of inestimable value. Through its use many parts can be repaired that otherwise would go to the scrap heap, thus saving not only the replacement cost, but many days of idleness in waiting for extra parts, and also the labor necessary to substitute the new for the old.

Flues

One of the greatest benefits derived from the use of arc welding by the various railroads has been the lengthened life of flues and the elimination of possibly 90 per cent of flue failures. The results have been obtained through arc-welding the bead of the flues to the back head.

Many railroads have installed arc welders for this purpose alone, with varying success. Some railroads have profited greatly while others have abandoned the practice of arc welding, claiming the process to be a failure.

In all cases it has been conclusively proven that the failures were due to one or more of the following causes:

(1) Experimenting with a view to accomplishing a single purpose.

(2) False economies in the purchase of welding iron.

(3) Improper preparation of the work before welding and lack of care following the operation.

(4) Indiscriminate selection of operators.

Discussing these points in order:

(1) Many roads insert the flues through the head without using copper ferrules and weld the bead to the sheet without any preparation. Where such welds break, which is sure to occur, arc welding is condemned. Other roads have belled the flues and had them welded without further preparation, with the same results. Many similar instances could be cited.

(2) To make an efficient weld a proper grade of iron must be used.

(3) The following rules will be of assistance in preparing the parts for welding.

(a) Under no circumstances weld a set of flues (that is, the beads to the back head) until they are thoroughly sand-blasted to remove the dirt and grease from the head.

(b) Prohibit the use of oil on the flues or on the prossers, rolls, and beading tools.

(c) Weld no flues until they have been properly prossered and beaded. [illegible]

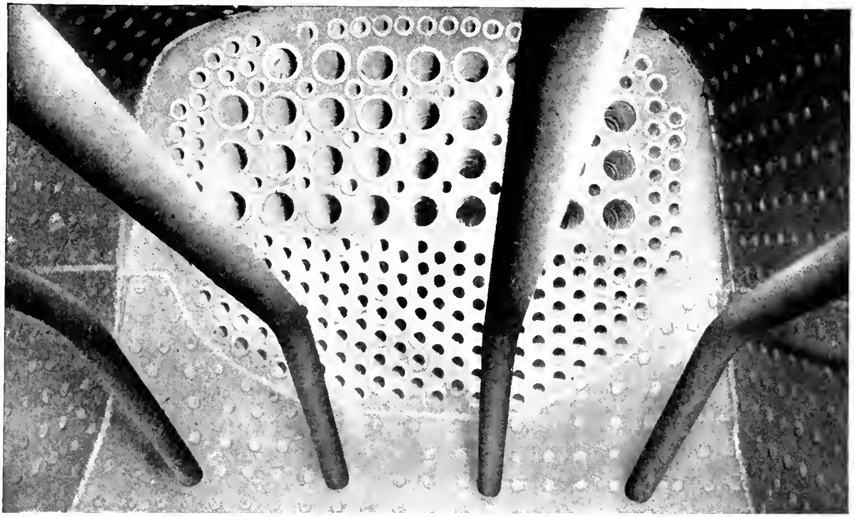


Fig. 1. Back Flue Sheet, Locomotive Fire Box; Tubes and Superheater Flue Beads Welded to Sheet; Patch Applied on Crown Sheet; Side Sheets and New Half Flue Welded in Place by Arc Welding

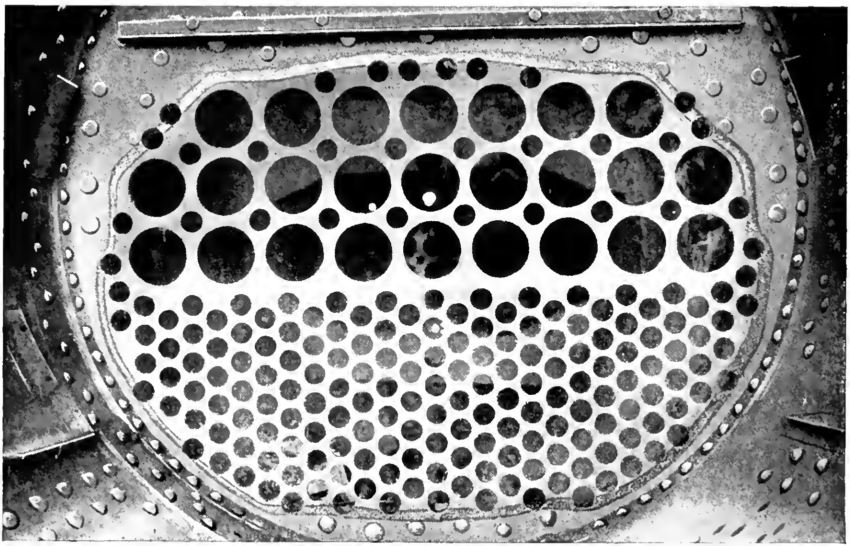


Fig. 2. Front Flue Head Welded in by Arc Process

burrs with a chisel and leave the joint between the flues and the sheet clean.

(d) Insert all copper ferrules at least $\frac{1}{16}$ in. back of the surface of the flue head, otherwise when they are rolled they will protrude from under the flue bead, which makes it almost impossible to produce an efficient weld. This alone is responsible for more electric-welded flue failures than any other cause, as the welding of copper to steel with the electric arc, except under certain conditions, is not practicable.

The flues, before welding, are inserted in the usual manner, with special attention to the above rules, particularly the one referring to protruding copper ferrules. The engine is then fired up to a testing pressure, or is run at least one trip over a division in order to give the flues a good setting to the head and to absorb the oil and grease from the head and back of the bead of the flue. Then the head is thoroughly sand-blasted, so that the fusing iron will adhere in welding.

The weld is started first at the bottom center of the flue or a little to the right or left, then worked up on one side to the top center, then up on the opposite side meeting at the top. Lap the weld at the point of completion to overcome blow- and pin-holes.

Experience has proven that it is a very harmful practice to begin the weld at the top and work to the bottom. The method that has proved most successful for over three years equally divides the weld on the head and the flue head, similar to Fig. 11. See that the weld does not extend over the top of the bead to form a corner in which fire cracks will develop.

The following table shows the increased mileage obtained from welded flues compared with those that were not welded, by one of the largest railroads on three of its largest divisions.

A careful study of the maintenance of welded flues that have developed leaks has been made, and the following method of remedying the trouble adopted as standard.

Remove all of the old electric weld from around the bead and the head, and then rebead the flue back tight to the sheet. Then thoroughly sand-blast the sheet. This will insure a longer life for the flues, as it eliminates the use of the prosser and rolls which tend to thin the flues and cause horizontal cracks to develop.

(4) This should not be taken as having undue reference to the employer. When there is a shortage of men the thing that is usually done is to select the first man who is willing to attempt the job. What is the result? There probably will be placed in a good efficient welding force a man who, until he is thoroughly educated in the details of welding, will be unreliable and his work must be carefully watched.

THE EFFECT ON FLUE FAILURES OF WELDING THE BEAD TO THE BACK HEAD WITH BARE ELECTRODE

	Month and Year	Total Miles Run	No. of Failures	Miles per Failure	
Division A	January 1914	280,674	11		
Division B		527,349	13		
Division C		682,651	54		No welding
		1,490,634	78	=17,816	
Division A	January 1915	245,609	3		
Division B		477,799	4		Not all
Division C		500,205	40		welded
		1,223,613	47	=26,034	
Division A	January 1916	294,316	3		
Division B		550,609	2		Second year
Division C		592,983	1		all welded
		1,437,928	6	=239,651	

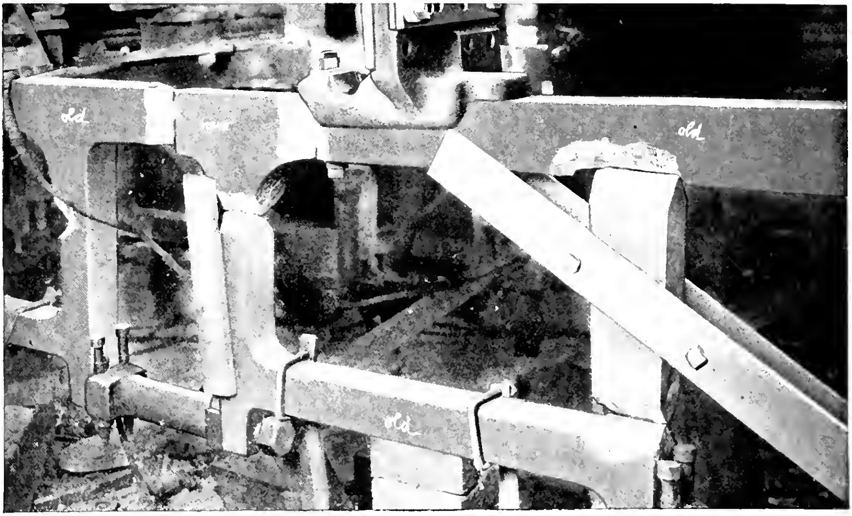


Fig. 3 Right Side Frame of Locomotive with Breaks Prepared for Welding; Work Done with Locomotive Assembled

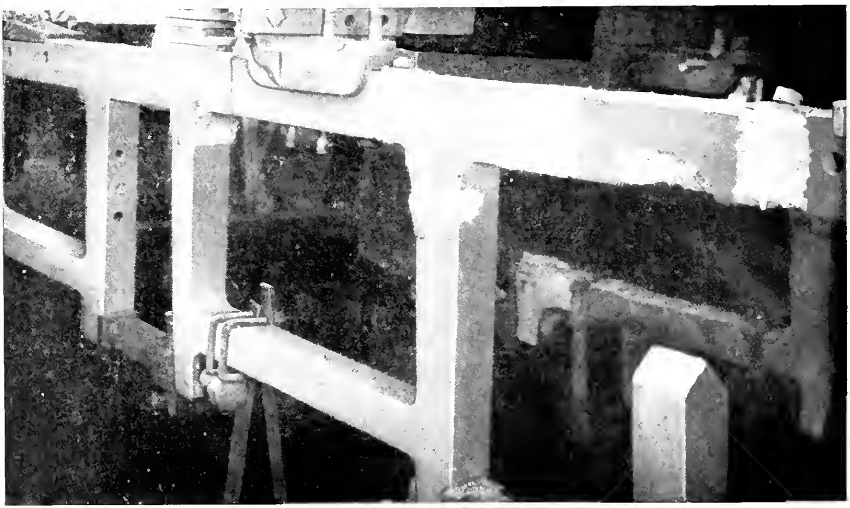


Fig. 4 Left Side Frame of Locomotive; Break Partially Prepared for Welding; Rubbed Spots Built up and Cracks Chipped out and Welded; Electric Arc Process Used

Fire-box Welding

All fire box welding is being done with the bare electrode, and a big saving is effected. Some roads not having had a single failure in three years' experience on this class of work. An enormous saving in time, labor, and material is being made by renewing the bad portion of the head, such as flue heads with a number of cracked bridges; and also by converting saturated engines into superheaters. The converted engines have only that part of the head renewed which takes the superheater flues, thereby saving the labor of flanging new sheets, riveting, and applying patch bolts. (See Figs. 1 and 2.)

Where a number of cracks run upward from the flues in the knuckle of the flue sheet, it is good practice to apply a patch the full width of the flue sheet, taking in the second row of flues; but where there is only one crack the method that has proven most successful is to remove the dome cap, and then "V" out the crack from the *water space side*, filling in with the bare electrode and reinforcing the sheet $\frac{3}{16}$ in. on the fire-box side.

Mud Ring Corners

When welding mud ring corners they should be thoroughly cleaned from oil and grease by either sand-blasting or with a roughing tool, and then caulked before the weld is started. Metal added should extend at least 6 in. beyond the corner of the ring and be applied to both inside and outside corners. (See Fig. 5.)

Frame Welding

In repairing broken frames the cracks should be "V'd" from both sides half way through to an angle of 45 degrees, leaving a $\frac{3}{16}$ in. opening. (Iron plates should be placed on the bottom of the frame to retain the metal when starting.) Fill in half of the "V" on one side of the frame and then fill in a corresponding amount on the opposite side, finishing the weld by completing the first side and finally the opposite side of the frame. (See Figs. 3 and 4.)

Flanges of Rolled Steel Wheels, Steel Tired Wheels, and Driving Wheels—Slid Flats and Shelled-out Places

These should be sand-blasted to remove all dirt and grease, provided the wheels are removed from under the engine, as sand-

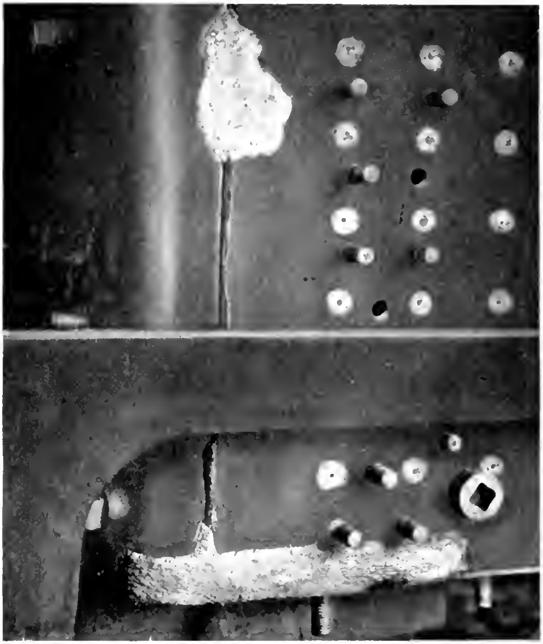


Fig. 5. Worn Outside Sheet of Mud Ring and Reinforcement where Rubbed by Spring Hangers

blasting wheels when under the engine is very detrimental to the motion work.

If the engine is fully erected the welders should be furnished with a small steel wire brush for removing dirt and grease before the weld is started. This operation can be performed in a great many cases without removing the wheels, and where possible this practice should be followed because of the saving in time. For example a heavy type freight engine was shopped because of slid flat spots on all eight driving wheels, these spots ranging from 3 to 5 in. long and $\frac{1}{4}$ in. deep. This engine was delivered outside the shop at 5:30 p.m. and with close and com-

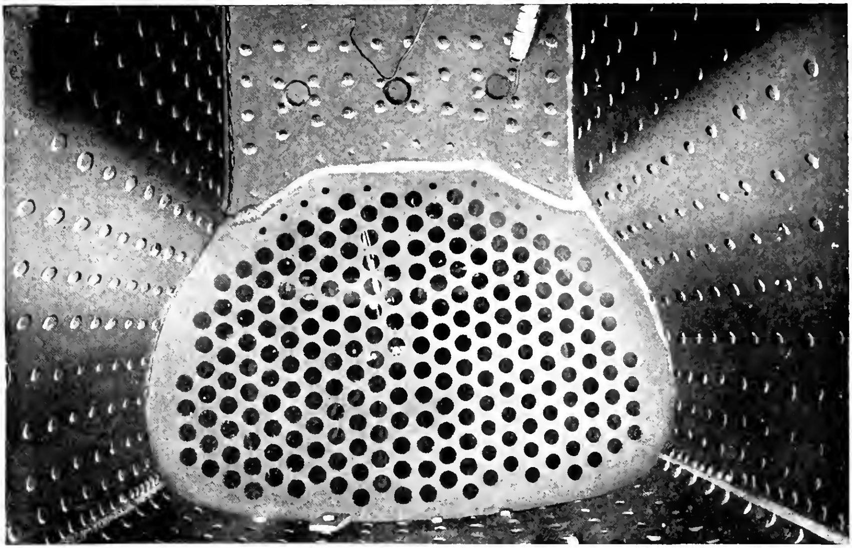


Fig. 6 Interior of Locomotive Fire Box, Back Tube Sheet Welded by Arc Process

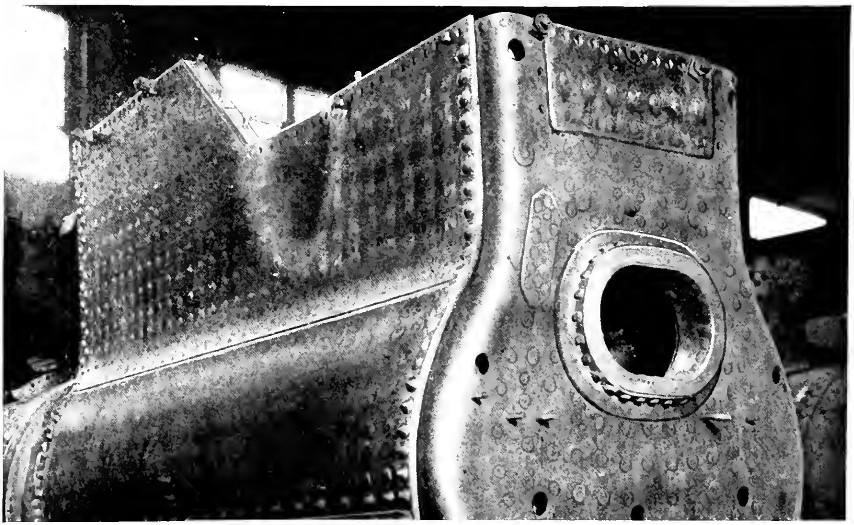


Fig. 7. Locomotive Boiler Being Changed to Stationary Type, New Half Side Sheets and Patch in Door Sheet; Work Done by Electric Arc Welding

petent supervision the engine was ready for service at 9 p.m. Consider the delay that would have been caused had the arc welder not been available. The tires had reached the minimum thickness and could not be turned; therefore it would have been necessary to place the engine over a drop pit, drop the wheels and remove the tires by a heating process, and apply new tires. This procedure would have required three days or more.

If it had been possible to turn the tires the wheels could have been removed and turned, then put back under the engine. The time required would depend on the situation of the lathe, bearing in mind that it would take about two days for removing and reassembling the wheels.

Stud Welding

A practice that has proved very successful is the welding of the studs on the smoke box front for door clamps. The studs are tapered to a point, and welded to the front, thus saving the time and labor of drilling and tapping the sheet. (Fig. 8.)

Locomotive Fire Boxes

Cracks in side sheets should be chipped V-shape to an angle of 45 degrees clear through the sheet with a $\frac{3}{16}$-in. opening. The parts welded should not be more than $\frac{1}{8}$ in. thicker than the original sheet after the welding is finished. When welding cracks in side sheets, the welding should be continued until the repair is finished to prevent the weld from cracking due to contraction. Cracks in side sheets 15 in. or over should never be welded.

Application of Patches to Side Sheets

All patches applied in side sheets should be either oval or round, and in applying the patch, all old metal should be removed, and the patch made $\frac{3}{8}$ in. smaller than the hole in which it will be welded; the side sheets as well as the patch should be beveled to an angle of 45 degrees. The patch should be set in position in the sheet with all bolts applied, allowing $\frac{3}{16}$-in. opening all around. The weld should be started at the lower side and welded one half way up on one side and then started at the lower opposite side and welded one half way up, completing the welds to the top in the same order. This is necessary in order to provide for expansion and contraction of the metal. After the patch is welded flushed, it should have at least $\frac{3}{16}$ in. reinforcement extending $\frac{1}{8}$ in. on each side of the weld.

Flues and Superheating Flues

Care must be taken to see that the copper ferrule is set back in the head at least $\frac{1}{32}$ in. to prevent the copper from working toward the fire side of the flue sheet and under the head of the flue. Before welding is started,

Fig. 8. Smoke Box Front with Studs Welded by Electric Bare Arc Process

it is necessary that all oil and grease be removed between the flue head and flue sheet. This can be accomplished by heating the engine in the shop to steam pressure or running one trip. Before welding is started the flue must be sand-blasted.

In welding, the operator should begin welding at the bottom of the flue and work up one side to top center, then return to the bottom and work up on the opposite side, meeting at the top. (Never begin at the top and work to the bottom.) This applies to both superheater and smaller flues.

In applying metal on the beads, it should never exceed the height of the bead or extend from the top of the bead to the flue corner, in which fire cracks will develop.

The best results will be had by making the weld about the same height as the bead, as shown in Fig. 11; but never permit the weld to extend over the top of the bead to form a corner in which fire cracks will develop.

Cracks in Top of Flue Heads

Cracks in the top of the flue sheet should be chipped to an angle of 45 degrees and an opening of $\frac{3}{16}$ in. made through sheet and

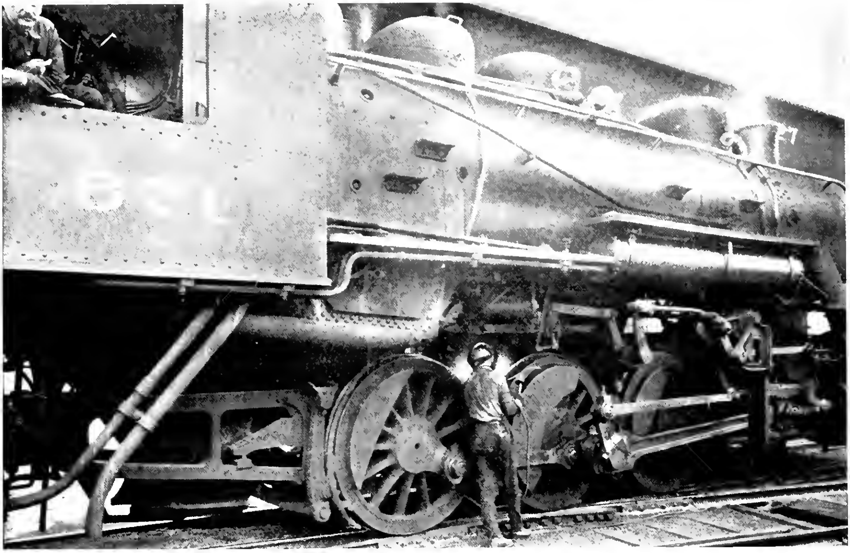


Fig. 9. Filling in Worn Flange on Locomotive Driving Wheel

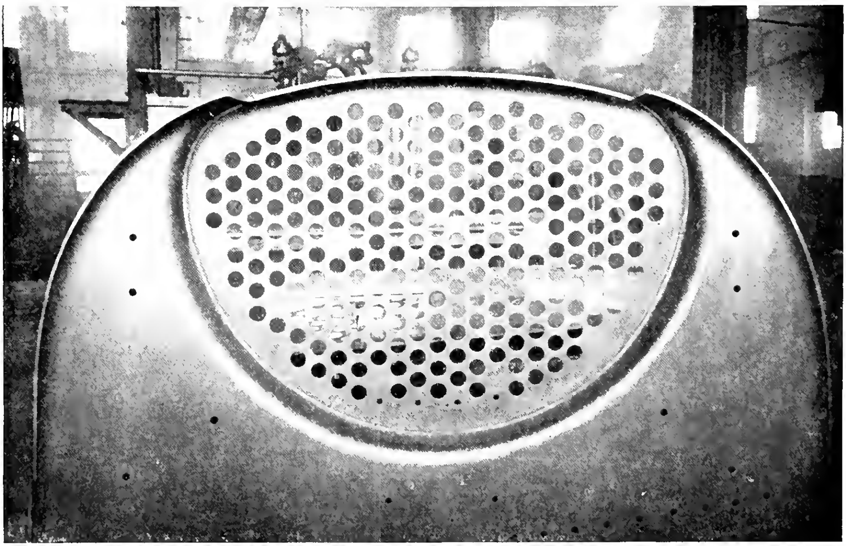


Fig. 10 Back Tube Sheet Welded to Head

welded from inside of boiler and reinforced from the fire box side.

Mud Ring Corners

Metal deposited should extend at *least* 6 in. beyond the corner of the ring, and be applied to both inside and outside corners.

Smoke Box and Tee Iron Holes

It is permissible to plug holes with boiler punchings, leaving a space of $\frac{3}{16}$ in. or more to apply electric weld on each side of the tee iron, and inside and outside of the smoke box holes.

Washout Plug Holes

In reinforcing washout plug holes, it is advisable to allow the plug to remain in the hole, and to apply the electric weld around the plug to the desired thickness, after which the plug can be removed, and the hole retapped. The weld will not adhere to copper plug.

Spring Hanger Rubs or Worn Frames

The frame must be free from rust and grease. When rub is $\frac{1}{4}$ in. deep or more, it is advisable to place a copper plate at the bottom of the rub to prevent the metal from running. Always see that the copper plate is knocked away after the weld is finished.

ARC WELDING OF TRUCK SIDE FRAMES

In repairing broken truck frames the preparation consists mainly in cleaning the frame of all traces of oil, rust, etc., before welding is begun.

Where cast steel side truck frames are found cracked similar to that shown in Fig. 12, the crack should be prepared for welding as shown in Fig. 13, as follows: The crack is cut out with a chipping hammer or oxyacety-

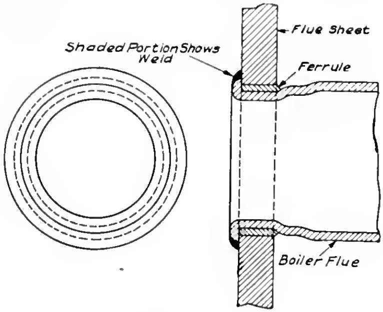


Fig. 11. Diagram showing Proper Method of Welding Flues to Flue Sheet

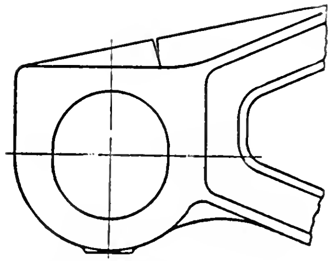


Fig. 12. Cracked Cast Steel Side Truck Frames

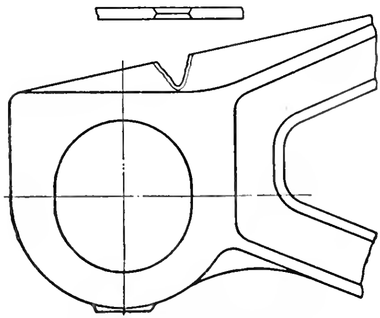


Fig. 13. Cracked Cast Steel Side Truck Frame Prepared for Electric Welding

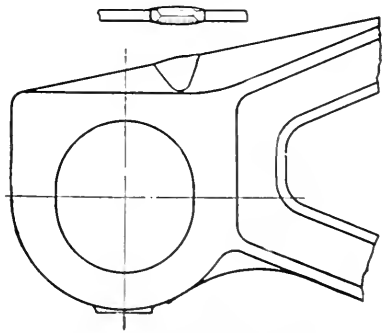


Fig. 14. Steel Side Truck Frame Prepared for Electric Welding

lene torch to provide a V-shaped opening, after which the opening is filled in as shown in Fig. 14, by depositing metal with the electric arc.

In beginning, the arc must reach the bottom of the groove, liquefying the metal at that point first. For this reason the groove or V-shaped opening in the frame must have an angle sufficiently large to allow the operator to get the metal clear through. The angle is usually 45 degrees. Care should be exercised in seeing that all the old oxidized and molten metal is removed from frame at the crack if same is prepared with the acetylene torch.

After the V-shaped groove is filled on both sides, a reinforcement, not exceeding $\frac{3}{16}$ in. in center of weld and tapering down to a feather edge, should be placed on the frame.

Bettendorf side truck frames should not be repaired by electric welding when the vertical flange on the top member of the journal box is cracked into the top of the fillet on top of the journal box. Such side frames cracked down through the vertical flange into the fillet should be scrapped.

No cast-steel side truck frame should be welded when found cracked more than 1 in. back from any edge of the frame. When found cracked more than 1 in., frame should be scrapped.

ARC WELDING FLANGES OF ROLLED STEEL WHEELS, STEEL TIRED WHEELS AND DRIVING TIRES

The following instructions are to be followed in building up flanges on rolled steel wheels, steel tired wheels, and driving tires by electric welding:

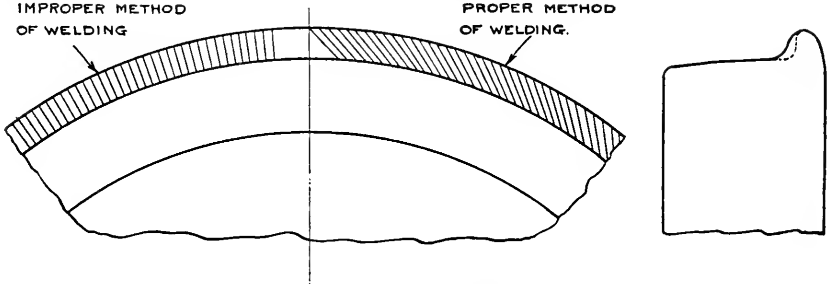


Fig. 15. Sketch showing Proper and Improper Method of Welding Wheel Flange

After each layer of metal is welded into the crack, it should be thoroughly brushed with a stiff wire brush to remove as much of the oxide as possible. Where the sand-blast is available, the results will justify the time necessary to clean the metal between the layers.

Any cast-steel side truck frame that is found cracked in any part of it similar to that shown in Fig. 12, regardless of whether it be Bettendorf, Andrews, or Vulcan type, and regardless of whether it be cracked in the top or bottom member of the frame, should be cut, prepared, and welded as described.

Instructions

Aside from the use of judgment in the application of arc welding, there are three rules which the operator must observe to get the best results.

(1) Hold a short arc.

(2) Don't let current be high enough to burn metal.

(3) Always weld to clean metal.

(1) Clean all grease and rust from flange with small steel wire brush, and do not start weld until metal is perfectly clean.

(2) Hold a close and steady arc, and never permit current to be high enough to burn metal.

(3) Build up flange by starting at tread and working towards top of flange, using rotary motion as shown in Fig. 15, so that the weld will be very even when finished.

(4) Build up flange to contour as shown on gauge.

RECLAIMING AXLES BY ARC WELDING

It has been found practicable to reclaim a considerable number of car and tender axles when worn beyond the limits for collar or shoulder, or reduced below the wheel fit limits prescribed by the M.C.B. Association. It is not desirable to reclaim axles worn to or near the limits of journal diameter, or having a diameter at center of axle below the limits prescribed by the M.C.B Association. Axles having full diameter at *E*, Fig. 16, and a journal diameter of not less than that shown in column *C* may have the wheel seat, collar, and journal shoulder built up by the arc welding process to the dimensions shown in Fig. 17. The sand-blast, when available, is the best means for cleaning axles for welding.

When building up axles strict attention should be paid to Fig. 16, in order that there may be enough metal to allow the axles to be finished to conform to Fig. 18.

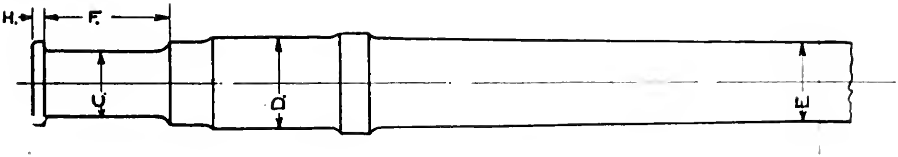


Fig. 16. Sketch of Axle, showing Limits of Wear Within which Repair by Electric Welding is Feasible

LIMITS OF WEAR (Fig. 16) — EXTENT OF WELDING (Fig. 17)

Size of Axle	DIMENSIONS IN INCHES								
	C	D	E	F	H	B	D	F	H
4¼ by 8	3⅞	5½	4 11/16	8½	¼	⅞	6	6 15/16	13/16
5 by 9	4⅝	6¼	5¼	9½	¼	⅞	6¾	7 15/16	15/16
5½ by 10	5⅛	6¾	5¾	10½	¼	⅞	7¼	8 15/16	15/16
6 by 11	5⅝	7⅜	6 5/16	11½	¼	⅞	7⅞	9 15/16	1 1/16

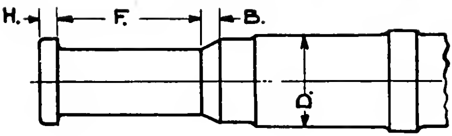


Fig. 17. Built-up Dimensions of Axle by Arc Welding

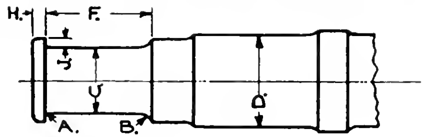


Fig. 18. Finished Journal

FINISHED JOURNAL (Fig. 18)

Size of Axle	DIMENSIONS IN INCHES						
	A	B	C	D	F	H	J
4¼ by 8	¼	⅝	4¼	5¾	8	⅝	½
5 by 9	⅛	¾	5	6½	9	¾	9/16
5½ by 10	⅛	¾	5½	7	10	¾	9/16
6 by 11	⅛	¾	6	7⅝	11	⅞	⅝

WELDING OF COUPLERS, KNUCKLES, AND LOCKS

It is very essential that a sufficient amount of current be used to penetrate the casting, there being no fear from expansion or contraction on this work, as it only requires building up metal on solid parts.

Work should be marked off by the car department before being given to welder, and also templet furnished welder to guide him in filling up the desired amount of metal required to make knuckle or lock same as original.

It is advisable to hammer the weld while hot—this to get an even and smooth surface.

Castings and Malleable Iron Parts

After thorough cleaning prepare the parts for welding by chipping, after which the parts should be clamped in position, and before the weld is started the parts should be heated from some external source. After the weld is completed the clamps should be allowed to remain on the casting until the metal is thoroughly cooled to prevent cracking from expansion.

Miscellaneous

In welding castings or worn places in sheets where it is desirable to preserve a hole, a copper rod should be inserted in the hole and the weld applied around the rod which is removed from the hole while the weld is still hot. The welding metal will not adhere to the copper rod.

It is permissible to weld over and around rivet heads.

Never weld over or around a stay bolt head.

Never weld around a crown bolt head.

Never apply a weld to the barrel of the boiler.

Grounding of Unwheeled Locomotives, etc., When Resting on Wooden Supports

When unwheeled locomotives, boilers, tanks, or other metal parts are supported on wooden blocks and where arc welding is used, ground wires should be applied.

The following table shows the work reclaimed at a small roundhouse and should not be compared with what can be saved at larger shops. It will be noted that the savings effected amounted to $379.68 on material reclaimed for a period of 24 days. The actual savings greatly exceed $379.68, as the reclamation of these parts enabled the shops to return the engines to service almost immediately.

MATERIAL RECLAIMED BY ARC WELDING FOR A PERIOD OF TWENTY-FOUR DAYS

Description of Work	New Price	Scrap Value	Amount Saved
6—Couplers	$144.30	$39.00	$105.20
28—Branch pipes	53.20	3.36	49.84
11—Worn piston rods	198.00	44.00	154.00
2—Main rod keys	.60	.08	.52
3—Tank valves	7.62	.50	7.12
2—Follower heads	4.80	.40	4.40
1—Crosshead pin	.30	.04	.26
8—Blower pipes	5.40	.66	4.74
3—Feed pipes	2.49	.30	2.19
2—Sand pipes	.28	.03	.25
2—Knuckle pins	.76	.08	.68
1—Equalizer	1.40	.20	1.20
2—Air pipes	2.98	.37	2.61
2—Units	8.40	2.00	6.40
2—Worn side rods	41.66	11.00	30.66
1—Blow off cock	8.80	1.40	7.40
2—Steam pipes	2.40	.29	2.11
Total	$483.39	$103.71	$379.68

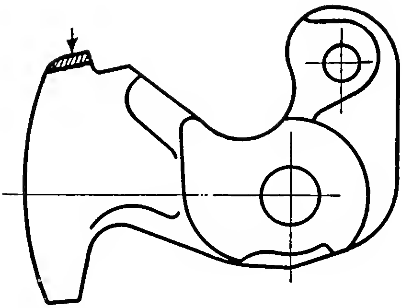


Fig. 19. Reclaimed Major Knuckle by Electric Weld

Major knuckle which has been reclaimed by building up with electric weld, 3/8 in., at a cost of $0.088. Cost of new knuckle $3.75, scrap value $0.39, cost to build up $0.088, making a total saving of $3.28 per knuckle.

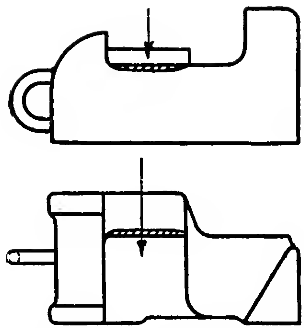


Fig. 20. Reclaimed Major Knuckle Locks by Electric Weld

Major knuckle lock which has been reclaimed by building up with electric weld, 3/16 in., at a cost of $0.067. Cost of new knuckle lock $2.00, scrap value $0.097, cost to build up $0.067, making a total saving of $1.84 per knuckle lock.

The reason for not showing the cost of welding is that this particular machine has already more than paid for itself, and at present labor and material are being charged to operating expense, so that it will readily be seen that the work reclaimed is clear profit.

In conclusion, I wish to impress the fact that the success or failure of electric welding depends solely upon the men doing the work. If they take a personal interest in the work, they can make it a success; if not, it will be a failure.

Electric Arc Welding in Tank Construction

By R. E. Wagner

Assistant Manufacturing Superintendent, Pittsfield Works, General Electric Company

The adequacy of electric welding, both with metallic and carbon electrodes, in manufacturing processes involving the fabrication of sheet metal, up to heavy boiler plate, needs no better demonstration than that afforded by the Pittsfield Works of the General Electric Company in the construction of many thousand of transformer tanks. Electric welding for this work has almost entirely replaced riveting, effecting a better construction, lower cost of manufacture, and a material reduction in the amount of noise and confusion in the tank shop. The author outlines the qualifications of a successful operator; and another very important point that is considered in detail is the intelligent study of the work in hand and its preparation for welding. Any neglect of either of these factors is certain to result in unsatisfactory work. The illustrations afford an idea of the extensive application of arc welding to tank construction, while the tables contain data that will be of assistance in determining the cost of the process. Editor.

Introduction

Arc welding, with metallic and carbon electrodes, has been used extensively in the construction of transformer tanks at the Pittsfield Works of the General Electric Company for a number of years, and has proved to be a reliable and economical factor in the building of large and small tanks made of sheet steel varying in thickness from $\frac{1}{16}$ of an inch to $\frac{5}{8}$ of an inch There have been produced more than 4000 large boiler plate tanks representing 400,000 ft. of welding with the metallic electrode, and more than 50,000 corrugated light steel tanks representing 2,500,000 ft. of welding with the carbon electrode.

Welding affords the most simple and effective means for making joints in steel plates that are capable of holding, without leaks, the warm oil which the tanks contain when in service. Riveted joints, which welding largely supersedes, could be made tight only after considerable caulking had been done on them. The use of welding has lowered the cost of tank making very materially and has reduced the amount of noise in the tank shops, thus making the tank makers' job more agreeable.

The apparatus required for electric welding is comparatively simple and very durable and, when once installed, the operator requires only his electrodes and a source of electric energy. With the protective devices afforded, there is no danger involved either from the nature of the process or from the electrical circuit, which is of such low potential as to be harmless even on direct contact with it.

A successful operator must be a man of honest temperament, conscientious, and interested to obtain the best results. He may be taught in a few days to hold the arc steady, and in about three months he may become an average welder. It requires some time for the operator to acquire the skill necessary to produce fairly uniform results in the different positions in which welding must be done. He must acquaint himself with the flow of metals in order to know definitely whether the current he has selected for welding is too high or too low; he must come to know if the plates being welded are penetrated deeply enough with the arc to form a good joint; he must observe the movement and condition of his work so that he can leave the least possible strain in the completed weld. These, and many other points, are to be learned principally through experience.

Preparation of the Work for Welding

It is essential that the work be properly prepared before welding is begun. A thorough study must be given the job in hand before any attempt is made to weld.

This study must first be applied to the effect of heat on the parts being joined; second, to the accessibility of the parts to be welded; third, to the nature of the strains to which the weld will be subjected; fourth, to the machining and assembly of the parts; fifth, to the position in which the weld can best be made; and sixth, to what condition the weld is to be left when finished.

(1) The effect of heat is to produce expansions and contractions which must be provided for whenever possible, otherwise severe strains may be left in the plates and welds that will materially reduce their effective strength or leave the work in a warped and distorted condition.

(2) The parts to be welded should be made accessible, so that welding may be performed thoroughly and the work of the welder simplified.

(3) A study of the strains to which the work will be subjected is necessary in order to determine the kind of weld that should be used. Different kinds of welds will be required depending on whether the strain is a direct tension, bending, torsion, prying, compressive, or a composite one, and whether the strength must be great as in a main seam or small as in a caulking weld.

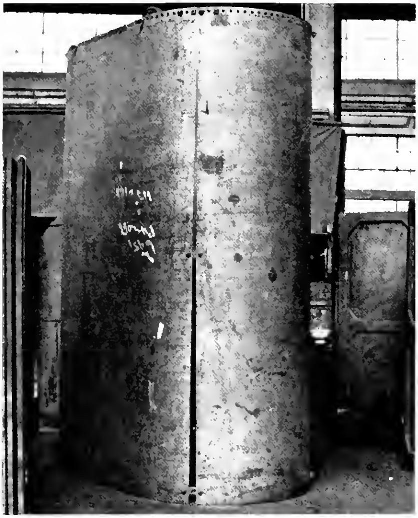


Fig. 1. Appearance of a Long Seam Ready for Welding. Note the bevel of the plate edges, the V shape of the seam, and the method of clamping

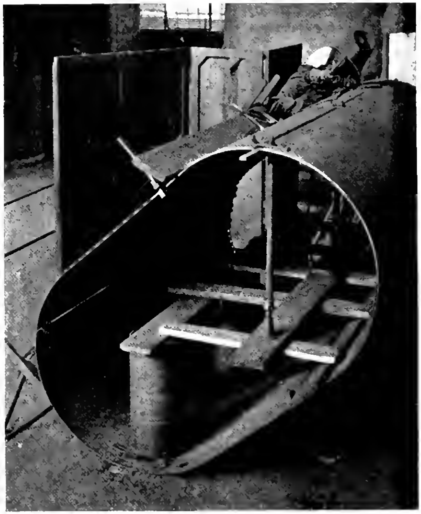


Fig. 2. Tank Similar to One in Fig 1 Placed for Welding, and the Welder Properly Outfitted Making the Weld

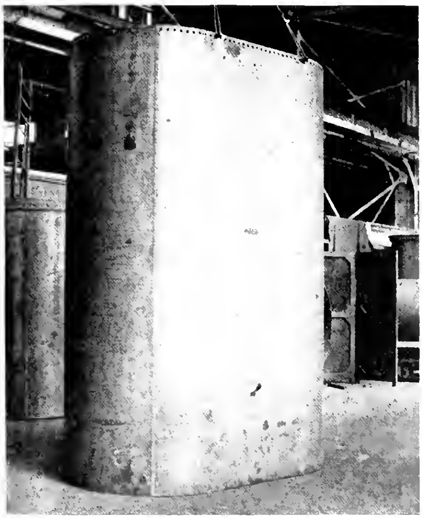


Fig. 3. A Finished Weld of a Long Seam. Note the uniformity in width and appearance of the weld

Fig. 4. Welding in Outlet Pipes and Locating Pins Before Assembling Base and Shell

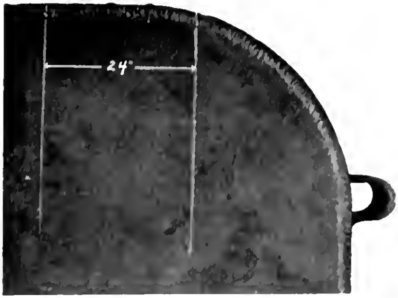


Fig. 5. Near View of Arc Weld in Base of Large Tank

Fig. 8. Drain Pipe and Locating Pins Welded in a Transformer Base

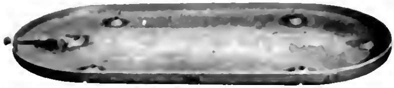


Fig. 9. All Bases with Welded-in Outlet Pipes and Locating Pins are Tested for Leaks Before Assembly on Shell. Test is made by building a wall of putty around each weld and filling the trough with kerosene. Joints must not show any leakage after a six-hour test.

Fig. 6. Note Corner Seam of Tank that was Welded Inside and Outside. The raised portion of the outside weld was ground off to make a smooth corner as the tank was afterward to be nickel-plated

Fig. 10. Shows Base and Shell of Tank Tacked and Wedged Ready for Welding. The shell plate is beveled on one side and the distance between it and the base is [illegible]. This arrangement enables the welder to weld the [illegible] and provides breathing space as the welding progresses. As the welder approaches the tacks they are cut away [illegible] movement of base and free it from unnecessary strain. When the welding is finished the bottom line of base is irregular. The base is afterward cut square.

Fig. 7. Oil Switch Tank Made of [illegible]-In. Sheet Steel

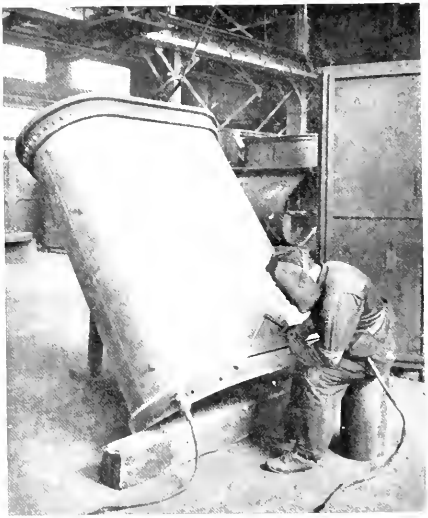


Fig. 11. Position in Which Tank is Placed When Outside Base Seam is Welded. The base and shell joint also have a light reinforcing weld on the inside

Fig. 12. Two-inch Tubes Welded into Shell. Note neat appearance of welds. There were 192 tube ends in this tank and when tested only three were found to leak. These were readily repaired. The normal leakage to be expected in welding of this nature is about one per cent

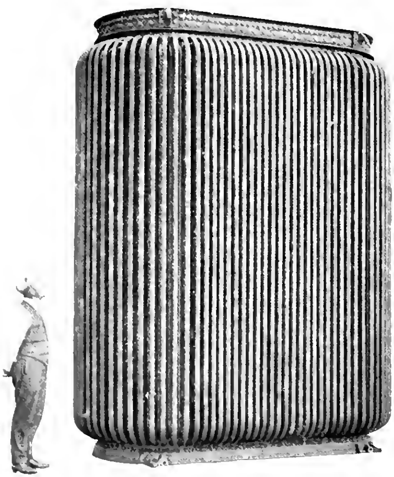


Fig. 13. Finished Tubular Tank with Base, Seams, and Tubes Welded

Fig. 14. Large Tank in Regular Test for Leaks. It is filled with water and allowed to stand for 48 hours. This tank with 90 ft. of welding did not develop a single leak. While filled with water the seams are given sharp blows throughout their length with a five-pound hammer

Fig. 15. Seam Prepared for Hand Welding with Carbon Electrode and Operator in the Position for Welding

Fig. 16. Corrugations Set Up Ready for Welding by Machine. The Clamps are removed as the arc approaches them

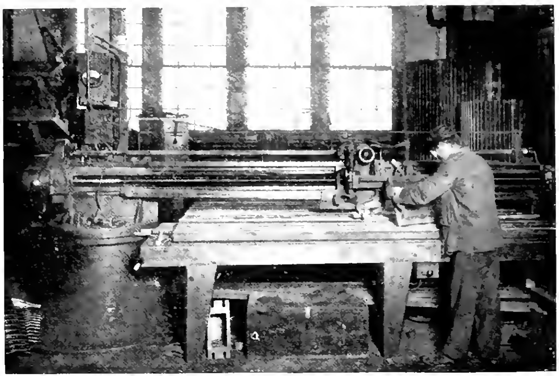


Fig. 17. Machine Operator Welding Seams 116 in. Long in Corrugated Sheets

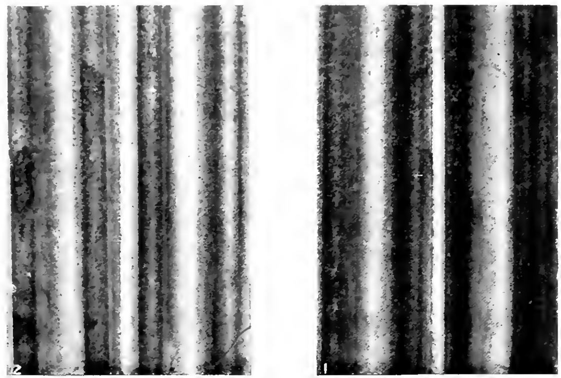


Fig. 18. Note the Comparative Appearance of Welds made by Machine (1) and Hand (2)

Fig 19. Use of Carbon Electrode with Metal Filler when Welding ¼-in Steel Bases to the Edges of Crushed Corrugations

Fig. 20. Use of Metal Electrode in Welding Steel Bands to Crushed Corrugations

Fig. 21. Tanks are Given a Static Water Test for 36 Hours and Then Carefully Inspected for Leaky Joints

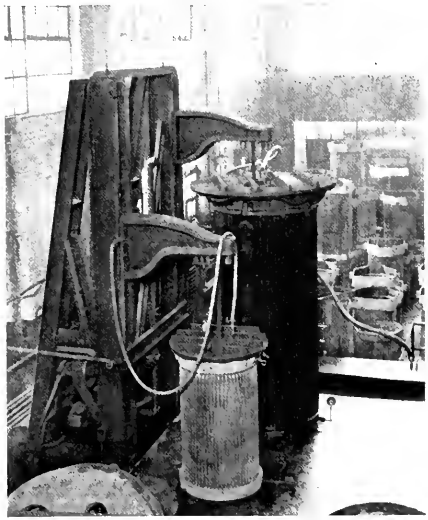


Fig. 22. Corrugated Tanks Under Hot Oil Pressure Test. The seams are carefully inspected for leaks while tank is under a 2-lb. pressure

Fig. 23. Electrically Welded Box Constructed for Experimental Purposes for the Electric Welding Committee of the Emergency Fleet Corporation. Box Under a Hydrostatic Pressure Test of 40 lb. Per Square Inch. Note bulging of plates

Fig. 24 Break in Corner of Box at 43 lb per Square Inch Pressure. The corner angle was bent considerably before the joint gave way It is difficult to calculate the strain in the joint at rupture on account of the composite nature of the stress, but it was probably in the neighborhood of 50,000 lb. per square inch

Fig. 25. Box Repaired and Under 15 lb Hydrostatic Pressure All repairs were made with welding. Bolt holes shown are filled with welded in metal

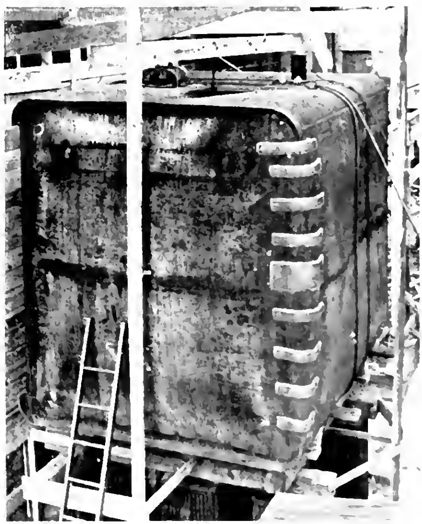


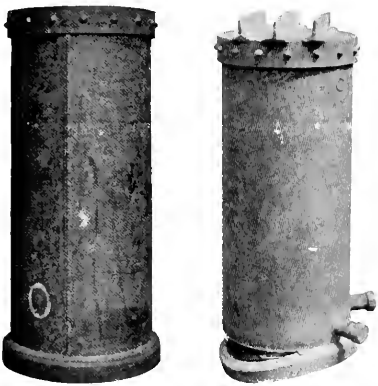
Fig 26 Box Un[illegible] V[illegible] The [illegible] including the b[illegible] from the position sh[illegible] Fig 25 The sides [illegible] arch in [illegible] snap subjecting welds [illegible] severe [illegible]

(4) The machining and assembly of parts must be such as to provide clean, proper, and sufficient contact surface for the welded-in portion and so arranged that a good and substantial joint will result.

(5) Whenever possible, the joint to be welded should be placed in the position that will be least arduous for the welder. Under this condition he will naturally do his best work This position is usually in a horizontal plane. Vertical and overhead welding may be done and done well, but these positions are more difficult and tiresome for the operator.

(6) Usually the welt or raised portion of the weld is left on, but it is sometimes necessary to remove this and have a plane surface; for example, around the top of a tank for the placing of a band, or if a tank is to have a special finish the entire raised portion of the weld may be removed. Under these conditions a light reinforcing weld may be made on the seam inside of the tank to compensate for the strength of the metal that has been removed.

The sketches included in Figs. 30 to 33 inclusive show some of the most common



Figs. 27 and 28. A Special Tank Welded with Alternating-current Arc and Bare Metallic Electrode. Tank was tested with hot oil and did not develop any leaks. Tank was then subjected to a hydrostatic pressure test of 700 lb. per square inch when it gave way in the transverse weld at the bottom. It is difficult to determine the breaking strain at the base as the joint was under a prying strain as well as tension, due to the dishing of the bottom plate under the pressure

methods employed in making preparations for various kinds of welds.

When long butt seams such as shown in Figs. 30, 31, and 32 are to be welded it is important, if the weld is to be made continuously

Fig. 29. Round Flat Plate Base Welded to Ring and Shell Note special construction made possible with arc welding

and in one layer, to allow for a contraction of the joint as the weld progresses; and unless this is done, undue warping and excessive internal strains may result. The amount of the allowance for this contraction varies slightly with the speed at which the work is done and is usually about 1½ per cent of the length of the weld. That is, if the seam is ten feet long the space between the plates at the beginning of the weld would be ⅛ in., and at the end 1½ per cent of 10 ft. plus ⅛ in. or 1.9 in. Clamps are used to hold the plates apart the proper distance and these are gradually released as the weld approaches them. The welder watches the opening; if it closes too quickly, he hurries his welding; and if it does not close quickly enough, he waits for it.

These precautions need not be taken in the case of very short butt welds, lap welds, or in long welds between bases and shells of tanks. These welds are either too short to develop any serious strains or the parts have an opportunity for breathing that dissipates the strain over a wide area.

Welding with Metallic Electrodes

Many of the accompanying illustrations show samples of metallic electrode welding work in tank manufacture. These indicate the

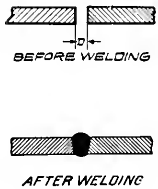


Fig. 30

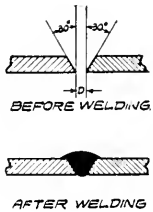


Fig. 31

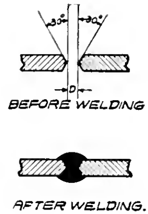


Fig. 32

PREPARATION OF SEAMS FOR BUTT WELDING

DIMENSIONS IN INCHES

Thickness of Plate in Inches	Space D
0 to 1/16	1/32
Above 1/16 to 1/8	3/32
Above 1/8 to 1/2	4/32
Above 1/2	5/32

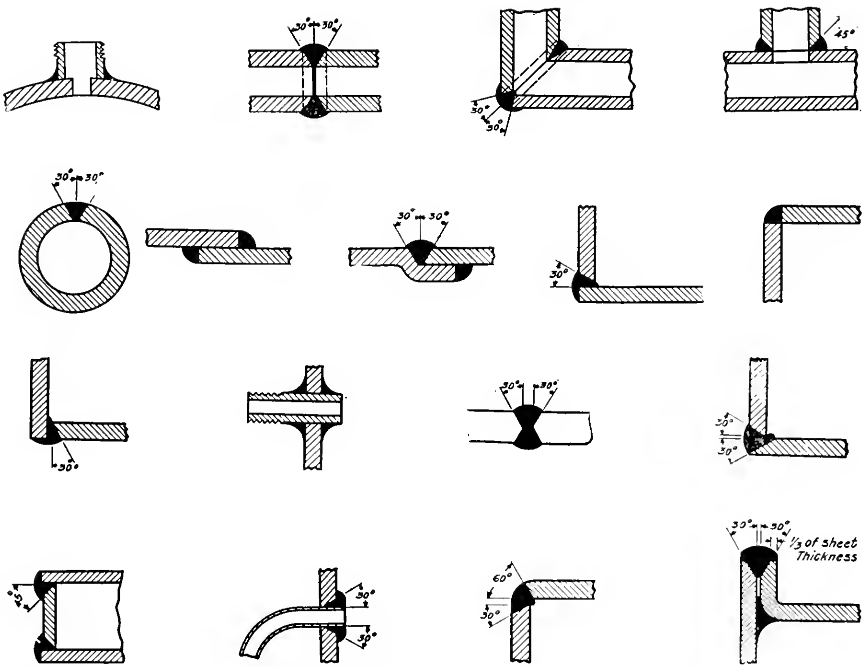


Fig. 33. Method of Making Various Types of Welds

great variety of work which can ably be done by arc welding with metallic electrodes, and show that such operations are thoroughly practical and the results neat and substantial.

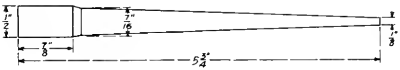


Fig. 34. Sketch of Molded Carbon Electrode

Other interesting work that has been accomplished by metallic electrode arc welding is also shown by the photographs.

Welding with Carbon Electrodes

The methods of welding applied to light corrugated steel tanks differ from those used on boiler plate tanks. The sheet steel of these corrugated tanks is principally of two thicknesses, $\frac{1}{16}$ in. and $\frac{3}{32}$ in., and the carbon electrode is used primarily to fuse together upturned edges of the sheets. The carbon electrode is also used in conjunction with a metal filler when placing the $\frac{1}{4}$-in. steel bottoms in the corrugated tanks. The metal electrode is also used on these tanks when welding the band to the corrugations. Welding as applied to corrugated tank construction is graphically portrayed in the illustrations of these tanks.

Electrodes

The bare electrodes that have been found satisfactory for tank construction are as follows:

(1) Norway or Swedish iron.
(2) Toncan wire.
(3) Armco bright hard-drawn electric welding wire.
(4) Roebling bright hard-drawn electric welding wire.

These wires and the tank steel have the analysis given in Table I:

TABLE I

Per Cent	STEEL PLATE	WIRE 1	WIRE 2	WIRE 3	WIRE 4
Carbon	0.25	0.049	0.10	0.078	0.185
Manganese	0.40	0.021	0.16	0.041	0.561
Phosphorus	0.025	0.025	0.010	0.011	0.037
Silicon	0.000	0.08	Trace	0.000	Trace
Sulphur	0.028	0.007	0.046	0.032	0.038

A satisfactory welding wire will melt and drop small particles uniformly into the weld and show deep biting into plates being welded. If there is considerable sputtering and large globules drop from the welding rod, the weld will be very porous and the deposited metal will be poorly united to the plates being joined.

The carbon electrode is of molded carbon and of the dimensions shown in Fig. 34.

TABLE II
Data on Electric Arc Welding with Bare Metallic Electrodes

THICKNESS OF PLATE	SIZE OF ELECTRODE	AMP.	KIND OF WELD	FT. PER HOUR	LBS. METAL DEP. PER FT.	SKETCH OF WELD
1/16"	1/16"	30	LAP	16	—	
1/8"	5/32"	100	LAP	11	.14	
1/8"	5/32"	95	BUTT	7.5	.23	
3/16"	5/32"	130	LAP	10	.22	
3/16"	5/32"	117	BUTT	6.3	.31	
1/4"	5/32"	140	LAP	6	.34	
1/4"	5/32"	137	BUTT	3.7	.50	
3/8"	5/32"	140	LAP	4	.47	
3/8"	5/32"	140	BUTT	2.5	.56	
1/2"	3/16"	150	LAP	3.6	.54	
1/2"	3/16"	150	BUTT	2	1.0	
5/8"	7/16"	165	LAP	2	1.0	
5/8"	7/16"	165	BUTT	1.33	1.45	
3/4" RIVET	5/32"	135	CAULKING	2 MIN. PER RIVET	.22 PER RIVET	
3/4" BAND 3/8" SHELL	5/32"	150	CAULKING	10	.22	
1 3/4" LOCATING PIN TO 1/2" BASE	5/32"	150	CAULKING	22 MIN. EACH	.4 PER PIN	
2" DRAIN PIPE TO 1/2" BASE	5/32"	150	SPECIAL	90 MIN. EACH	2. LBS. EACH	
2" BOILER TUBE TO 1/2" OR 5/8" PLATE	5/32"	135	SPECIAL	3 MIN. EACH	.13 PER. TUBE	

TABLE III
Data on Electric Arc Welding* with Carbon Electrodes

THICKNESS OF PLATE	KIND OF WELD	AMP.	FT. PER HOUR	FT. OF WELDING TO CONSUME ONE CARBON
1/16"	HAND	37	12	9
1/16"	MACHINE	50	24	14
3/32"	HAND	50	12	7
3/32"	MACHINE	65	24	11
SKETCH OF WELD.				

*EDGE WELDING OF CORRUGATED SHEETS. NO METAL ADDED.

Apparatus

The apparatus used for welding consists of a 75-volt, 150-kw., direct-current generator driven by an induction motor. The generator is furnished with a regulator that maintains a constant potential at the main busbars. A curve-drawing voltmeter indicates to the foreman when there are any excessive variations in voltage.

One of the important features in the performance of good welding with this system is a source of constant potential. This condition reduces the opportunity for variations in current supplied the arc. A fairly constant current is essential to the uniform deposition of homogeneous metal in the weld.

Each welder's circuit leaves the constant-potential buses and passes through a contactor with an overload relay, a rheostat with remote control head, a reactance coil, and thence to the welder's panel which is fitted with the necessary receptacles so that the operator may plug in and obtain current and control when required. The welder's panel is fitted with an ammeter so that he may adjust his current to known values which are specified for different thicknesses of plate. Connections are so made that the work is always the positive side of the circuit. Each circuit has a capacity of 200 amperes.

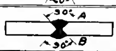
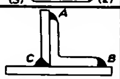
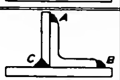
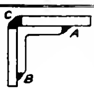
Alternating-current Welding

While all the results thus far noted in this article have been obtained with direct current, equally good results may be obtained with alternating current, although the alternating current arc is more difficult for the operator to hold.

One can do alternating-current welding at any frequency between 12½ and 500 cycles and with voltage as low as 90 volts. Very good results may be obtained at 110 volts and 60 cycles. The current required for a given thickness of metal is approximately the same as for direct-current welding. The carbon as well as metallic electrode may be used.

TABLE IV

DATA ON ARC WELDED BOX

SKETCH OF WELD	WELD NO	AMP AT 75 V. D C.	LBS. OF WIRE USED	LBS. OF WIRE DEP LAST	LBS. WIRE SCRAP ENDS	FT. OF WELD	TIME HRS.	KW-HRS.	% SCRAP ENDS WIRE	LBS WIRE DEP PER FT.	KW HRS PER LB. OF WIRE DEP	FT. WELD PER HR	KW HRS PER FT. OF WELD	% OF TIME WELDER IS WELDING	SIZE OF WIRE	WELDER NO
	1-A	140	5.75	5.00	.75	11.60	4	23	13	.43	4.6	2.9	1.98	55	3/16"	58
	1-B	150	4.50	4.00	.50	11.6	2.5	17	11.1	.345	4.3	4.6	1.47	61	"	70
	2-A	150	7.25	6.50	.75	11.6	2.75	19	10.3	.56	2.93	4.12	1.64	61	"	58
	2-B	140	5.00	4.50	.50	11.6	2.38	16	10	.39	3.56	4.9	1.38	64	"	70
	3A(1)	150	12.25	10.75	1.50	12	5	42	12.2	.90	3.88	2.4	3.47	74	"	58 70
	3A (2+3)	160	9.00	8.25	.75	22.03	4.08	26	8.3	.36	3.15	5.6	1.18	53	"	58 70
	3B-(1)	150	9.00	8.25	.75	8.83	3.5	25	8.3	.93	3.03	2.52	2.82	63	"	58 70
	3B (2+3)	150	9.75	9.00	.75	17.66	3.42	23	7.7	.51	2.66	5.15	1.3	60	"	58 70
	3C-(1)	165	8.75	8.00	.75	8.83	3.67	26	8.6	.91	3.25	2.4	2.94	57	"	58 70
	3C (2+3)	150	9.25	8.13	1.13	17.66	3.83	26	12.1	.62	2.17	4.6	1.41	58	"	70
	4-1 A+B	150	9.00	8.25	.75	19.2	4.92	28	8.3	.43	3.4	3.9	1.46	50	"	58
	4-1 C	150	13.50	12.25	1.25	9.6	4.78	35	9.3	1.28	2.85	2.0	3.65	65	"	62
	4-2 A+B	150	8.50	7.75	.75	19.2	4.67	30	8.8	.4	3.88	4.1	1.56	57	"	70
	4-2 C	150	12.75	11.50	1.25	9.6	4.75	37	9.8	1.2	3.2	2.0	3.85	69	"	66
	5-1 A+B	150	10.50	9.50	1.00	17.56	4.92	36	9.5	.54	3.8	3.56	2.05	65	"	66
	5-1 C	150	7.00	6.25	.75	8.78	2.75	17	10.7	.71	2.72	3.20	1.94	55	"	66

(Continued on next page)

TABLE V

DATA ON ARC WELDED BOX

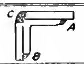
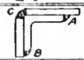
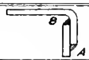
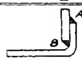
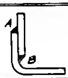
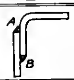
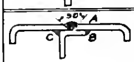
SKETCH OF WELD	WELD NO.	AMP. AT 75 V. D.C.	LBS. OF WIRE USED	LBS. OF WIRE DEP. + LOST	LBS. WIRE SCRAP ENDS	FT. OF WELD	TIME HRS.	KW-HRS.	% SCRAP ENDS WIRE	LBS. WIRE DEP. PER FT.	KW-HRS. PER LB. OF WIRE DEP.	FT. WELD PER HR.	KW-HRS. PER FT. OF WELD	% OF TIME WELDER IS WELDING	SIZE OF WIRE	WELDER NO.	
	5-2 AB	150	11	10	1	17.56	5	35	9.1	.57	3.5	3.5	2.0	62	3/16"	58	
	5-2 C	150	8.25	7.25	1	8.78	2.75	15	12.1	.83	2.1	3.2	1.71	48	"	62	
	5-4-B	150	5.75	5.25	.5	8.78	1.92	11	8.7	.60	2.1	4.6	1.25	51	"	31	
	5-4-A	155	6	4.5	1.5	8.78	4.25	21	25.	.61	4.67	2.1	2.4	43	"	70	OVERHEAD
	5-4-C	160	7	6.25	.75	8.78	3.33	20	10.7	.71	3.2	2.64	2.27	54	"	62	
	5-3-A	160	7	6.25	.75	8.78	3.5	25	10.7	.71	4	2.5	2.85	63	"	43	VERTICAL
	5-3-B	150	5.75	5.25	.5	8.78	2.33	17	8.7	.60	3.24	3.77	1.94	65	"	66	
	5-3-C	160	9.75	9	.75	8.78	3.16	23	7.7	1.32	2.66	2.8	3.76	65	"	62	
	6-1-A	150	10.25	8.75	1.5	9.6	4.33	33	14.6	.91	3.76	2.2	3.43	68	"	58	
	6-1-B	150	7	6.5	.5	9.6	2.33	21	7.7	.68	3.25	4.1	2.2	83	"	66	
	6-2-A	160	9	7.75	1.25	9.6	4.33	25	13.9	.81	3.23	2.2	2.6	48	"	70	
	6-2-B	150	7	6	1	9.6	2.33	18	14.3	.63	3	4.1	2.58	69	"	62	
	7-1-A	150	6.5	6	.5	11.6	2.75	20	7.7	.52	3.33	4.2	1.72	65	"	66	
	7-1-B	150	7.5	6.75	.75	11.6	4.75	27	10	.58	4	2.44	2.32	51	"	70	
	7-2-A	150	5.5	5	.5	11.6	3.66	16	9.1	.43	3.2	3.20	1.38	39	"	70	LIGHT WELD
	7-2-B	150	7.5	6.75	.75	11.6	4.75	27	10	.50	4	2.44	2.32	50	"	62	

TABLE VI

DATA ON ARC WELDED BOX

SKETCH OF WELD	WELD NO.	AMP. AT 75 V. D.C.	LBS. OF WIRE USED	LBS. OF WIRE DEP. AND LOST	LBS. WIRE SCRAP ENDS	FT. OF WELD	TIME HRS.	KW-HRS.	% SCRAP ENDS WIRE	LBS. WIRE DEP. PER FT.	KW-HRS. PER LB. OF WIRE DEP.	FT. WELD PER HR.	KW-HRS. PER FT. OF WELD	% OF TIME WELDER IS WELDING	SIZE OF WIRE	WELDER NO.	
	7-3-A	160	7.75	7.0	.75	11.6	3.83	23	9.7	.6	3.3	3	2	53	3/16"	58	
	7-3-B	150	6	5.5	.50	11.6	3.83	22	8.3	.47	4.0	3	1.9	51	"	62	
	8-A	150	7.25	6.5	.75	11.6	3.5	20	10.3	.56	3.1	3.3	1.72	51	"	58	
	8-B	150	6.25	5.75	.5	11.6	3.08	18	8	.5	3.1	3.8	1.55	62	"	66	
	9-A	150	15.5	13.75	1.75	12	9.75	49	11.3	1.15	3.5	1.2	4.07	45	"	58 70	
	9 B+C	150	11.75	10.25	1.5	22.8	5.33	34	12.8	.45	3.3	4.3	1.5	56	"		
MISC. WELDING DRAIN PIPE, BRACES, CHANNEL, PLUGGING HOLES, MAN HOLE.		150	16.75	15.5	1.25	38	18.2	66	7.5	.41	4.2	2.1	1.70	32	"	58	
TOTAL* AND AVERAGE△ VALUES FOR ALL WELDING.		150△	334*	289*	35*	501*	165*	1011*	11△	.60△	3.4△	3.0△	2△	60△	3/16"		

Welded Steel Box for Emergency Fleet Corp.

The following interesting results were obtained on a large steel box 12 ft. by 9 ft. by 10 ft. made of ½-in. tank steel plate for the information of the Electric Welding Committee of the Emergency Fleet Corporation.

The principal data to be obtained from the construction and testing of this box were:

(1) Could a structure of this character be built close to drawing dimensions and without excessive distortion of the plates and parts?

(2) Would the structure be strong and capable of withstanding severe shocks and distortions without serious ruptures?

(3) What would be the detail costs and time required to build such a structure?

The entire box was electrically arc welded, no rivets being used in its construction. The welded joints are neat and attractive in appearance; and the substantial character of the work is revealed in Figs. 23 to 26 inclusive which are photographs taken during the severe tests imposed upon the box. The box has been subjected to alternate applications of 15 lb. internal hydrostatic pressure and 22 in. vacuum more than 200 times and has not developed any serious leaks or failures in the welds. These results show that condition (2) is satisfied to a considerable degree.

Tables IV, V, and VI give in full detail the results obtained while making various kinds of welds on the box. These results were obtained by six different welders and give fair average values that may be expected on a job of this character.

The cost of work done on the box was as follows:

Cost of welding	$151.28
Fabricating and assembling	157.94
Preliminary testing	50.00
Welding wire	30.00
Material	651.30
Total cost	$1040.58

The rapid development and extensive applications of electric arc welding during the past few years has put it on a substantial basis and within a short time; and it is expected to be an important economical factor in many manufacturing processes and in the present emergency.*

*The writer is indebted to Messrs. C. J. Cole and F. C. Heneau for valuable assistance in obtaining data on which this article is based.

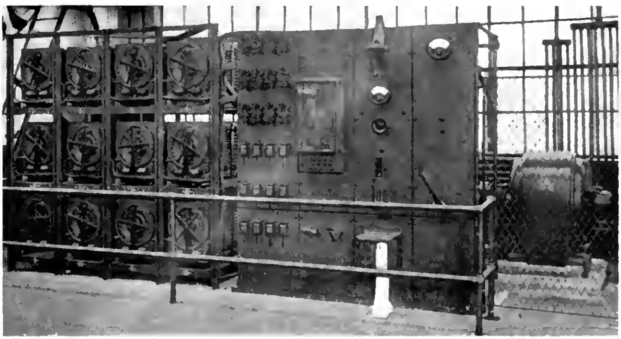


Fig. 35. Main Station Designed for Twelve Welders

An Electrically Welded Freight Car

By Joseph A. Osborne

Chief Electrical Engineer, American Car and Foundry Company

The gondola car described in this article was constructed largely by electric spot welding seven years ago, and since its completion has been in constant use. The results accomplished by the builders appear remarkable when we consider that there was no precedent by which to be guided. The work involved even the design and construction of a large spot welder, as no apparatus of sufficient capacity was to be found on the market at that time. The service record of this car demonstrates fully the practicability of electric spot welding for railway car construction, and in the words of the author, it is to be hoped that the adoption of the electric welding process in this field will not be delayed longer.—Editor.

During the year 1911 while endeavoring to improve upon the manufacture of steel freight cars, it was decided to adopt some form of electric welding. Up to this time, however, the process seemed practical only in welding metal of small gauge. Electric arc welding was not in universal use, and besides it was not suitable for car construction. The method of spot welding was chosen as being the most practical as well as quickest method. It was found, however, that there were no welders built which would weld the sections necessary in car construction, the commercial machines available having only a capacity of two $\frac{3}{16}$-in. sheets. Feeling that the method was practical and could be used on heavy work, a machine was designed in an attempt to accomplish the desired results.

This machine, shown in Figs. 1 and 2, consisted of a structural steel frame arranged with a 66-in. throat and provided with a recess for the reception of an 85-kw. transformer having a primary voltage of 400, and a secondary open circuit voltage of 25. The primary winding was provided with taps for regulation, and further regulation was accomplished by means of a choke coil. These combinations gave the necessary control.

Pressure was applied by means of a hand wheel, but subsequent machines were equipped with air cylinders for applying the pressure. Copper electrodes 3 in. in diameter were used at the jaws, the welding points having a diameter of $\frac{3}{4}$ in. It was found that perfect welds could be made with this machine through three sheets each $\frac{3}{4}$ in. thick, or $2\frac{1}{4}$ in. total thickness.

When the machine promised to be a success, the work of building a test car was begun. It was the intention to eliminate as many rivets as possible in the car structure, but due to inaccessible positions it was found that a number of rivets in the underframe could not be replaced by welds. However, about 85 per cent of the rivets were replaced with welds.

In the underframe welds were used for cover plates on cross bearers for the body bolsters at each end and for cover plates for the center sill. It was necessary to use rivets to hold the hinge and side bearing castings, as cast iron cannot be welded. The entire superstructure of the car was welded except the ladder irons. It was thought inadvisable to use welds here, as each rung is held by only two fastenings, and should one fail a man might lose his life.

Some difficulty was experienced at first in making the welds on the actual work because of the inexperience of the men, but after a few trials and experiments, however, the men became proficient and the work progressed rapidly. The time required to weld the car was about two thirds of that necessary to rivet a similar car. This was due to the fact that all fitting, drilling, and reaming of holes and inserting hot rivets were eliminated. Besides this saving in time, all laying out and punching of holes was also eliminated. The greatest saving, however, was in the elimination of all drills and reamers, with the consequent repairs and replacement of bits, and also the saving in air hose. Air power, when used for hammers and compression riveters, is very expensive when the breakage of the system and maintenance are considered. Therefore, the actual power required to weld the car was about one third of that required to rivet a similar car.

The tests on the completed car were very interesting. It was found to be much more rigid than the riveted construction, and it showed no slip or permanent set. The car was loaded to 150 per cent capacity, and after the usual tests were applied, it was given a road test to ascertain whether weakness would develop. The car was put into actual service by the Burlington Road and has been in operation since that time. The writer made a number of personal inspections of the car on the road and it showed no signs of failure.

The use of the spot-welding process in building a heavy structure, such as a freight car, seven years ago was a radical departure from the general practice at that time. Adverse opinions and criticisms were offered. I am pleased to state, however, that the experiment was a success and that our

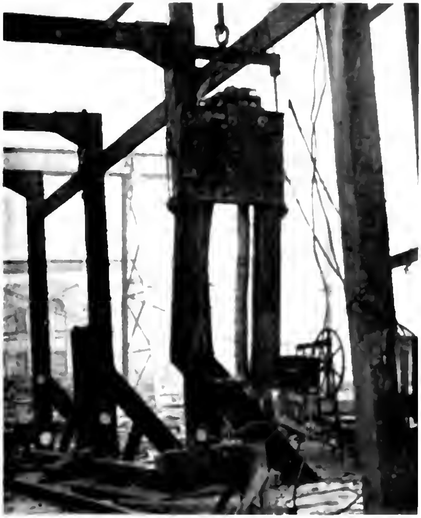


Fig. 1. General View of the Welding Machine. Note that the pressure was applied by means of a handwheel. The transformer was provided with various primary combinations to obtain different voltages

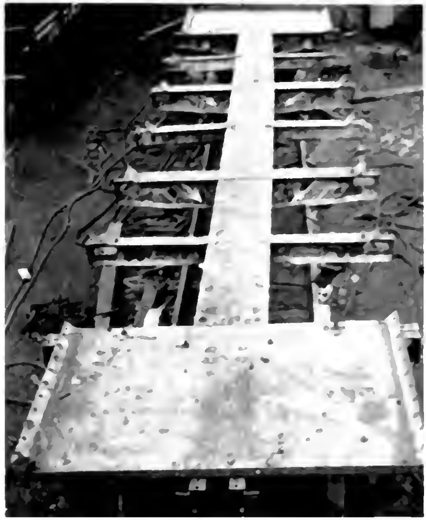


Fig. 2 ... Over the Center ...

Fig. 3. Plan View ... W... C...

Fig. 4. W... F... F...

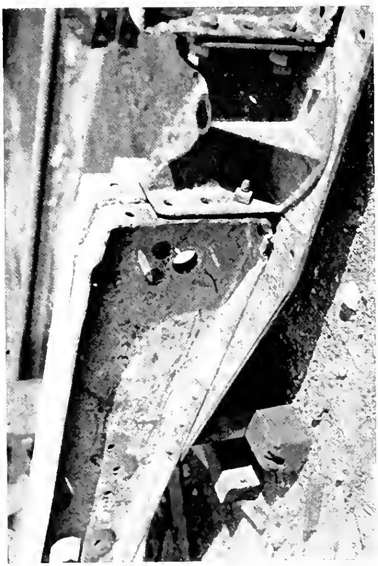


Fig. 5. A View of the Body Bolster. This is the member which carries the entire load of the car at each end. Note the bottom cover plate was spot-welded to the flange of the diaphragms. The three rivets shown are for the purpose of holding in place a cast-iron side bearing

Fig. 6. Process of Welding the Top Chord Angle to the Side Sheets. Note the splice plates used in joining the side sheets. Where this splice plate is welded to the top chord angle it was necessary to weld through four thicknesses of metal as a side stroke was used on the outside for a splice plate

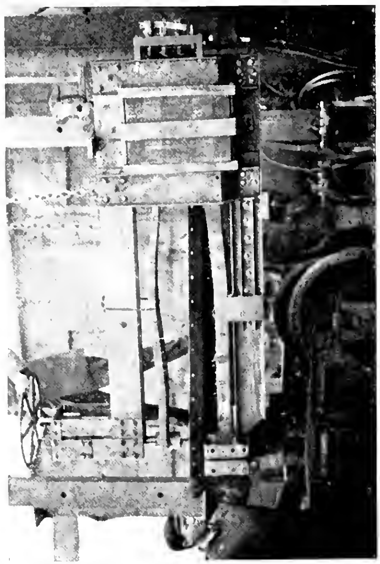


Fig. 7. Welder in the Act of Welding the Floor Sheet to the Body Bolster

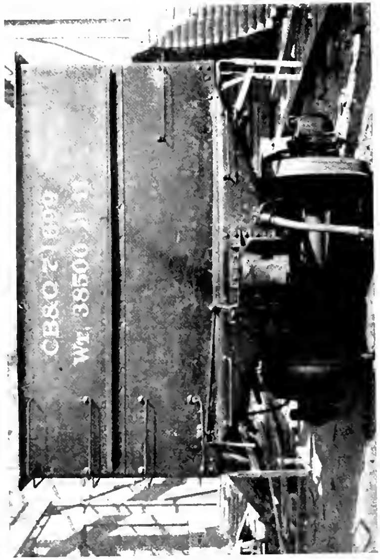


Fig. 8. One of the Main End Sheets. The bath tub section stiffener across the center of the sheet was spot-welded in place as well as the top chord angle, as indicated by the arrows in Fig. 7

original calculations as to just what could be expected of spot welding have proved correct.

The severe strains and abuse to which a freight car is subjected, together with the constant vibration, would soon wreck the car if the welds had not been properly and efficiently made. I believe that this severe test of the process has demonstrated the fact that spot welding for heavy structures is absolutely practical and reliable. It has demonstrated that riveting can be replaced in almost all instances. The ease of manipulation, as well as the great saving, will no doubt cause this process to be universally adopted. Much education, however, is needed to bring the advantages of the process to the attention and serious consideration of structural engineers. It is to be hoped that the adoption of the electric welding process will not be delayed longer.

The accompanying photographs were made during the construction of the car and will prove interesting in showing the various stages of manufacture.

Electric Welding at the Erie Works General Electric Company

By H. Lemp and J. R. Brown, Jr.

Engineer and Assistant, Erie Works, General Electric Company

The contents of this article and those of Mr. Wagner, and Messrs. Collins and Jacob in this issue show show conclusively that the electrical manufacturer's recommendation that electric welding be applied to other lines of manufacture and construction is backed up by a record of successful development of the processes and application of them to the electrical industry.—Editor.

Electric welding is being used quite extensively in various lines of work at the Erie Works of the General Electric Company, and the quality of work speaks very highly for the electric processes of welding. Though looked upon rather unfavorably at first by some of the foremen of the departments in which it could be used to advantage, electric welding has won their favor with its merits, and has effected a saving in time, labor, and materials.

The welding equipment is located in the various buildings throughout the works, where it is most convenient. Canvas screens and booths are built around the arc welders for protection, and guards are placed about other equipment where there is danger from the current. The equipment now in constant use consists of:

Arc welder sets	Butt welders
Spot welders	Brazing machine

Arc Welding

The arc-welding sets are provided with motor-generator sets, both portable and stationary, using 600-volt, 3-phase, alternating current for the motor. There is also one alternating-current welding set in use.

Quite a variety of work is being done in arc welding, but the most extensive use to which we have applied it is in the welding of locomotive cabs and bodies, turbine exhaust hoods, and gear housings. In these lines of work welding has proved far superior to the old process of riveting. The amount saved in the actual welding of a locomotive body may be estimated at from 25 to 30 per cent, while the cost of laying out and drilling for riveting is entirely done away with. The cost

Fig. 1. Electrically Welded Locomotive Cab

of the welding wire is less per pound than that of the rivets. The time required by one man in arc welding is but slightly more than the time required to rivet, which requires three men. After the body is welded, it is gone over and the welded joints ground smooth with an electric emery wheel. The absence of rivets gives the body a more attractive appearance, being perfectly smooth, and the construction is even more rigid than the riveted body.

The cost saved on the turbine exhaust hoods is not quite so much, due to the time required and the expense of straightening or lining up, the construction being far more rigid and having less tendency to give. However the saving is estimated at from 18 to 25 per cent over the method of riveting.

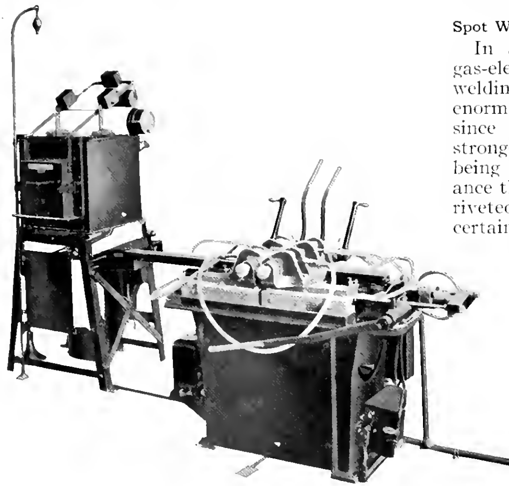


Fig. 2. 20-kw. Thomson Welder

On the gear housings the cost of welding is very little less than the cost of riveting, as only the seams of the housing are welded, the case being riveted to the cast-steel web or frame. But the joint, aside from being neater, is far more satisfactory as there is no chance for loose or leaky seams.

Another very economical use of arc welding is the repair of broken castings, or castings that have certain flaws in them, such as blow-holes, sand holes and depressions. The saving here can hardly be reckoned, for in many instances the casting would be scrapped could it not be repaired by arc welding. The saving is greater than in any other branch of arc welding, if the value of the casting is compared with the scrap value of the unrepaired casting.

The repair of broken parts of machinery, gear wheels, motor frames, bases, etc., by welding is similar to the class above, in that the saving cannot be estimated, though in a large plant this saving is no small item.

Except for the repair of castings, such as filling in large holes or cracks, metallic electrodes are used.

Spot Welding

In assembling the radiator hood for a gas-electric set, the amount saved by spot welding over riveting is 81 per cent. This enormous saving has paid for the spot welder since its installation. Aside from being stronger, the welds are unnoticeable after being painted, giving a much neater appearance than that of the older hoods which were riveted. Spot welding on sheet metal within certain sizes has completely taken the place of riveting, being so much quicker, neater, and more satisfactory.

The other spot welder in service has a rather unique use. The problem of lining the space between the outer and inner walls of the large electric locomotive bodies with felt, is performed as follows: A special handle made of heavy copper and so constructed as to grasp a large size cobbler's nail with only the head exposed is attached by means of a heavy lead to a spot-welding transformer. A push button located conveniently on the handle operates a contactor on the primary circuit, giving the operator complete control. A nail is inserted in the end of the handle and is then spot-welded to the outer wall of the locomotive body at intervals of six or eight inches. The felt is then applied and tin washers pressed down over the nails, holding the felt firmly to the wall. The nail is then bent over to hold the

Fig. 3. Spot-welded Radiator Hood

washer in position. The old method of partitioning the walls and filling in with pieces of felt was more expensive as well as less satisfactory.

Butt Welding

The two butt welders in the plant are being worked to their full capacity, and a great many new uses have been found for this process of welding. A small 5-kilowatt Thomson butt welder is located in one of the tool rooms and is used chiefly for welding band saws. The saving realized in this one operation alone is extremely large when compared with the old method. The two ends of the broken saw are ground square on a small emery wheel; a scale is scraped from it

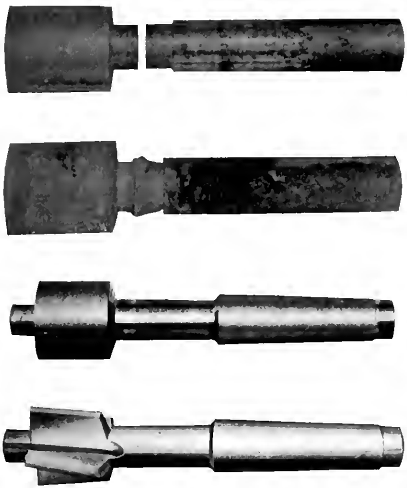


Fig. 5. Various Stages in Manufacture of Machine Tool Formed by Electrically Butt-welding High Speed Steel to Shank of Ordinary Machine Steel

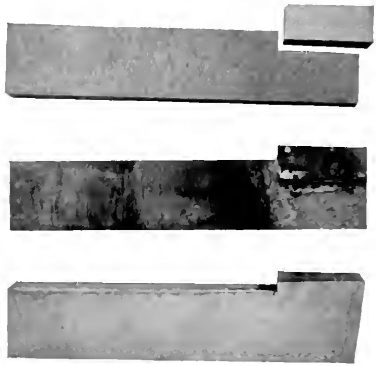


Fig. 6. Electrically Butt-welding High Speed Cutting Face to Machine Tool Shank

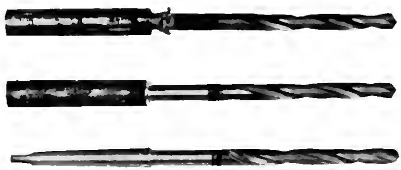


Fig. 8. High Speed Drill Electrically Butt-welded to Shank of Ordinary Machine Steel

Fig. 7. Electrically Butt-welding High Speed Cutting Face to Machine Tool Shank

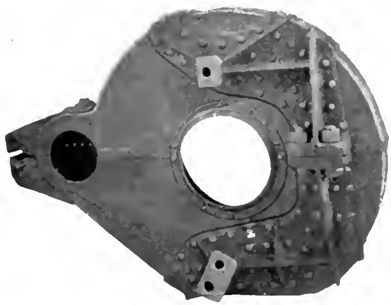


Fig. 9. Gear Housing on Which the Seams are Electrically Welded

and the two ends placed in the two jaws of the butt welder, allowing about ¼ in. at each end to project from the jaws. Bringing the two ends together, lightly at first until they begin to fuse, pressure is applied. After the weld has been accomplished, the

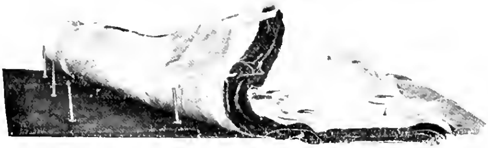


Fig. 10. An Application of Electric Spot Welding to Secure Felt Lining in Place Between Outer and Inner Walls of Electric Locomotive Bodies

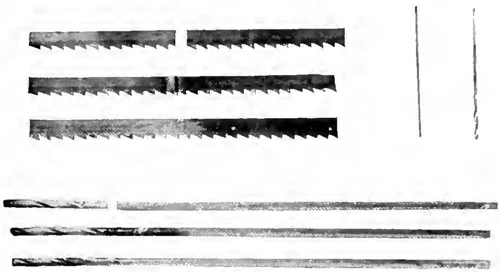


Fig. 11. Other Useful Applications of Butt Welding

saw is reclamped, allowing a couple of inches between the jaws, and the saw brought to a dull red, thus annealing the weld. The saw is then removed, the welded joint being ground or filed to a smooth finish. The whole operation requires only from two to five minutes, and shortens the saw only ½ in., the joint being smoother and stronger than by the old method.

The larger butt welder, of 20 kw., is located in the tool making department, and its chief use is welding high-speed tool steel to carbon steel. Machine tools that require a long shank for clamping in lathes would be very expensive were it necessary to make them entirely of high-speed tool steel. By welding the cutting portion of the tool, which is of high-speed tool steel, to the less expensive carbon steel for a shank, a tool is obtained which is not only as satisfactory but more economical. The time required to weld a lathe tool 1 in. by 1¼ in. cross section is less than two minutes; the welded joint being stronger, requiring less skill, and being accomplished in less than one eighth of the time required by the old method. In a similar manner, and with as great a saving, extension drills, counterbores, etc., are welded.

A new feat accomplished with the electric butt welder, which met with complete failure when attempted with forge welding, is the welding of a small block of Stellite about an inch square by an inch and a half long, in one corner of a carbon steel lathe tool. This requires a double weld which seems impossible to accomplish in forge welding, yet is quickly and satisfactorily done with the electric method.

Brazing Machine

The brazing machine now in use in the plant is similar to the larger spot welder, except that the two contacts on the brazing machine are of carbon. The chief use to which this machine is applied is the brazing together of the ends of coils in the construction of large armatures. Heretofore these were riveted, requiring quite a bit more time and giving a poorer electrical contact.

Fig. 12. Electrically Welded Turbine Exhaust Hood

Research in Spot Welding of Heavy Plates

By W. L. Merrill

Power and Mining Engineering Department, General Electric Company

The author's record of experiments points to a new and enlarged field for the application of electric spot welding. That the process will eventually supersede riveting to a large extent in all structural iron work is more than probable. With properly designed apparatus and appliances the possibilities of spot welding in the various metal trades are almost unlimited.—Editor.

The success which has attended the application of electric welding in the construction of fabricated ships, and the assurance that this method of fastening will eventually supersede riveting to a large extent in the structural work of buildings and bridges and in the manufacture of boilers, etc., indicates that the efficiency of one more mechanical process will be increased by "doing it electrically."

Fig. 1. Electric Welding Machine of 36 Tons Pressure Capacity and 100,000 Ampere Current Capacity, Built to Determine the Practicability of Spot-welding Heavy Plates. The transformer (at the right) furnishes the welding current, and the meters in the box (at the left) were used while making the initial welds to record the values of current, pressure, and time

The following record of experiments in spot-welding heavy plates reveals the probability that a new field of application for spot welding will be developed.

In the latter part of the summer of 1917 a decision was made to build a heavy spot-welding machine to investigate the possibilities of welding plates of 1/4-inch thickness and greater. As there were no data available on electrodes, pressures, or currents for welding heavy plates, a machine of very large capacity was designed. The pressure and current limits of this machine, Fig. 1, were decided upon the basis that should larger apparatus than this be required, the scheme of welding would probably not be a feasible one.

A 2000-kv-a. transformer, having a capacity of 100,000 amperes at 20 volts, and partially shown in the right-hand portion of Fig. 1, was built to supply the welding current. The hydraulic arrangements were made to give pressures up to 36 tons at the electrodes. Motor-generator sets of 500- and 6000-kv-a. capacity were assigned to this work.

The first part of the investigation consisted of determining the type of electrode which would stand up under these heavy current densities and high pressures. Various complicated types of electrodes were built and tried.

but the final choice, all things being considered, was the simplest type of all.

From the nature of the service, it was apparent that the very high current densities at the point of contact of the electrode and the work necessitated some form of cooling. It was found by experimenting, however, that it was impossible to water-cool the electrode sufficiently to give it a reasonable life if the section of the electrode was carried up any considerable distance from the work with the same cross-section as the area of the electrode at the weld.

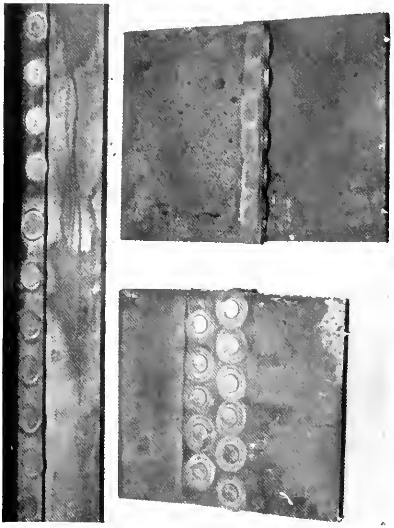


Fig. 2. Samples of: A 3-inch Angle Iron Spot Welded to a Half-inch Thick Plate; Two 12 by 18 by ½-inch Thick Plates Welded in a Double Row Using Buttons (Thin Steel Disks) under the Electrode; and Similar Plates Welded in a Single Row Using Elongated Electrodes which make a Practically Continuous Weld.

Therefore, it was obvious that heavy masses of electrode material (copper) were necessary in the immediate vicinity of the point of contact so that, during the time of welding, the electrode, due to its great thermal capacity, would absorb heat and keep the point of the electrode at a safe temperature. With this construction it was possible to have a very large cooling surface in the top of the electrode, and passing water through this part at the time of welding and between making welds kept the points of the electrode cool enough for all practical purposes.

The life of the electrode under these operating conditions was considered sufficient as it was the intention to have several electrodes available at the machine so that when the points became worn by dragging the plates through them, or blunted, due to usage, they could be removed from the machine and the fresh ones supplied. The original electrodes were then to be swedged back to shape. Later experiments, however, demonstrated the practicability of using thin copper cups formed between dies. These cups are designed to clip over the point of electrode proper, can be renewed when worn, and are inexpensive.

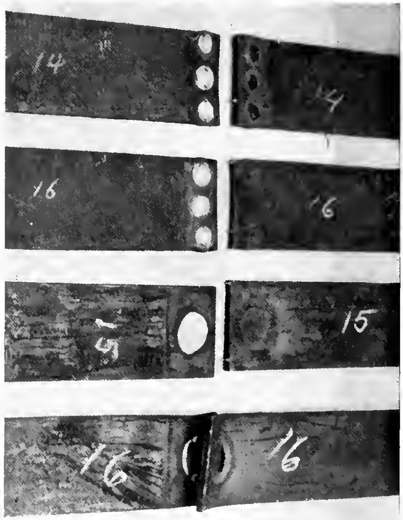


Fig. 3

Top and Top Center: ½- by 7-inch plates welded in three spots and pulled apart. Buttons used on top one and none on top-center one.

Lower Center: Same size plates and welded spot as in sample at bottom but current used was too low to make a proper weld. Weld sheared at 71,400 pounds equivalent to a stress of 23,800 pounds per square inch in the plate.

Bottom: ½- by 6-inch plates welded in a single 2½-inch spot and pulled at 106,400 pounds equivalent to a stress of 35,400 pounds per square inch in the plate. This sample is an example of how welds may tear out when made too near the edge of the plate.

During the first attempts at welding with this machine, gratification was felt to find that the limits in pressure, current, and voltage which had been chosen were not only ample but were considerably in excess of any requirements which might be encountered.

In anticipation of there being a very narrow zone of current, voltage, and pressure for making successful welds, there was installed automatic recording current and voltage devices and a special hydraulic recording device was built which would plot the three curves automatically against seconds of time. These measuring devices were located in the box shown in the left-hand portion of Fig. 1.

It was felt that with the three variables, current, pressure, and time, any one of which might necessarily be varied through a considerable range during the process of making the weld, these devices would be necessary in order that after a successful weld had been made it could be intelligently reproduced.

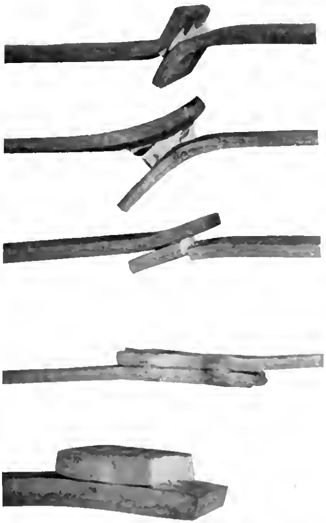


Fig. 4. Test of Samples ½-inch and 1-inch Thick showing Tearing Action when a Single Row of Welded Spots is Used and the Jaws of the Testing Machine are Offset to Accommodate the Displacement. It is, therefore, obvious that, as with rivets, more than one row of spots should be used.

Tests of the first welds, however, showed that there was a considerable range in pressure, current, and time which would make successful welds. Having the conditions approximately correct at the time of starting, there appeared to be no reason for changing these during the welding operation. The automatic recording apparatus was therefore abandoned.

The method of procedure was briefly as follows:

Pieces of plate of various thicknesses, about one foot square, were welded together using different typse of electrodes, different currents, and different pressures. They were then sheared through the middle of the weld,

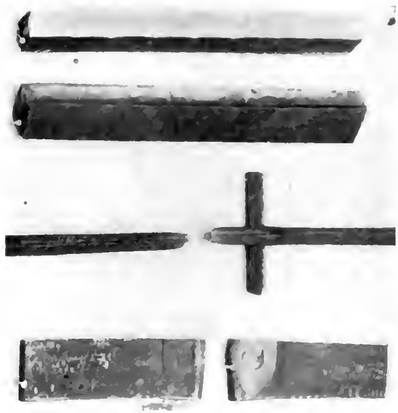


Fig. 5. Samples of Welds made in the Machine Shown in Fig. 1

Top: ½-inch thick plates sheared through the row of welded spots for examination.

Middle: ⅝- by [illegible] steel bars welded [illegible] and pulled, break occurred away from weld.

Bottom: ½-inch thick steel plates welded in a single ¾-inch spot, broke in tension at 27 000 pounds which is approximately the elastic limit of the sample.

as shown in Fig. 2, which, by the way, is a moderately severe test of a weld. The different welds were then examined and checked with the observed data of current and pressure, and more welds were produced, and the same sequence followed until the zone of time, current, and pressure for a given thickness of plate were determined.

Samples of plates 6 inches wide and 7 inches wide and 18 inches long, of various thicknesses, were welded together and pulled in the testing machine at the Rensselaer Polytechnic Institute, Troy, N. Y. These first samples were very good and showed that the strength of the weld was about that anticipated. The action of the testing machine, as is shown in Fig. 3, was to bend the samples and rip them apart instead of shearing them; this action occurred because of the necessary offset in the testing machine to fit the samples.

A number of samples were then prepared with two rows of welds, differently arranged and spaced; also, with butt strips. These joints were strong in tension and in most cases were stronger than the cross section of the material itself.

It will be noticed from an inspection of Fig. 1, that there had been used in the foregoing investigation a single transformer having its positive and negative terminals

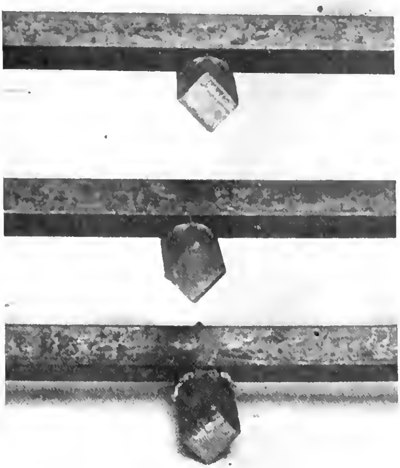


Fig. 6. Samples Similar to Those Shown in Fig. 5

Top: Heating too slow as compared with the pressure used.
Middle: Heating and pressure properly adjusted.
Bottom: Heating too fast for the pressure used.

connected directly to the electrodes. This arrangement made a loop in the supply leads to the electrodes and naturally introduced considerable reactive drop which lowered the power-factor of the system and which required that the primary voltage of the transformer be adjusted for each width of plate when plates of different widths were inserted, due to the added inductance in the circuit caused by the plate being inserted in the loop. It was obvious, therefore, that the elimination of this variable feature would make the machine more practical; that is, it would be possible to set the machine for a certain thickness of plate and reproduce welds regardless of the width of the plates being welded. The connections to the transformer were then changed and all the leads put on the same side of the plate being welded, and two spots were welded at a time instead of one. Experience has shown that this is a perfectly feasible method of welding and that the only point to which special attention would have to be given is the obtaining of equal pressure on each spot so that both welds can be made in the same length of time. The resulting conclusions were that a successful machine for heavy plate welding with a deep throat should have two transformers, one on each side of the work with leads brought directly to the electrodes. The two secondary windings of the transformers, when the plate is inserted and the pressure applied, would then be in series. This is the method adopted for the trial machines now under consideration. In case only one weld is desired, or it is impossible to so locate the work that only one weld can be made at a time, it is obvious that with a machine of this construction a small dummy plate can be placed between the other electrodes.

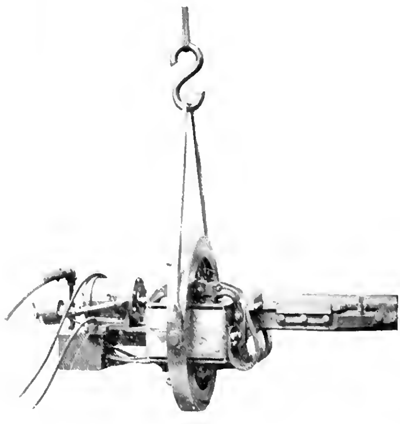


Fig. 7. Welding Machine for Splicing and Welding Iron Mesh Re-enforcing for Concrete Ships

While it may take longer to make a heavy, spot weld than to drive a rivet in the shop by a bull riveter, yet electric welding will eliminate the laying off, punching, reaming, and bolting of the various parts as required by the bull riveter, and will result in a large over-all gain in time, labor, and cost.

Spot Welding and Some of Its Applications to Ship Construction

By H. A. Winne

Power and Mining Engineering Department, General Electric Company

Starting with the early practice of spot-welding light-weight constructions, Mr. Winne describes in the following article the extension of this type of welding to heavy work, notably the fabrication of the parts used in the construction of ship hulls. He discusses the advantages of spot welding over riveting with respect to strength, time, and labor, and outlines the limitations of the spot welder. In conclusion, he describes in detail the application of spot welding to the construction of ladders and gratings and to the plugging of misplaced holes.—Editor.

Resistance welding, more commonly termed "spot" or "butt" welding, has been in use on rather a small scale in various manufacturing processes for a number of years. The butt welder has been used for splicing wire, for welding chain links, metallic rims for automobile wheels, and kindred purposes. Spot welding has been particularly successful in superseding small riveting operations on light sheet metal work, such as the manufacture of automobile bodies, filing cases, and similar products. In fact, spot welding has practically been confined to operations in which the plates welded have not exceeded ⅛ in. in thickness.

The application of spot welding to heavier material has always been considered a possibility, and in fact, some small amount of work has been done along this line, as witnessed by the production of a welded car* in the shops of the American Car & Foundry Company. In the past eighteen months, the necessity for an enormous and ever increasing production of ships has made the subject of heavy welding a very active one; and a large amount of research and developmental work has been done to produce successful welding machines and to convince the shipbuilders and ship insurance companies that a spot-welded joint can be made more quickly than a riveted joint and equally strong.

In an article† in this issue there is described in detail the research work on spot welding that was carried on by the General Electric Company, which work resulted in the building of three heavy welders that are now being tried out in actual shipyard service. In the following, no attempt is made to describe the construction or method of operation of these machines, as these subjects are fully covered in another article.‡

The advantages of spot welding over riveting are an increase in strength of joint, saving of time, saving of labor, and saving of material. The disadvantages of welding as compared to riveting, applied to plates of the thickness used in shipbuilding, are the welder is heavy and cumbersome and requires a considerable amount of single-phase power.

Advantages of Spot Welding

Obviously, a welded joint can be so made that it will be stronger than the plate itself, by simply making enough spots. Usually two rows of spots, the spots being staggered and spaced from each other a distance about equal to the diameter of the spot, are sufficient to produce this strength. Of course, the foregoing presupposes good welds, but that this is a justifiable premise is proven by the results of tests.† In any riveted joint, a considerable portion of the plate is of necessity cut away in drilling or punching the rivet holes, with consequent decrease in strength. No matter how many rivets are used or how they are placed, it is impossible to obtain either a lap- or butt-riveted joint which is 100 per cent efficient.

The saving of time in favor of the welded joint occurs not in the actual welding operation but in the elimination of the preliminary operations which are necessary for the making of a riveted joint. Before the riveted joint is made the plates must be accurately laid off and the holes punched in them. Then, when the joint is put together, if the holes in the two plates do not line up correctly it is necessary to ream them or to use a drift pin. In making a welded joint no punching is necessary, and there are no holes to be lined up; the welds may be spaced by the eye. A further saving of time is effected due to the fact that a smaller number of welds than of rivets is required for the same strength of joint. Considering the total time required for all operations, there will be a saving of from 25 to 50 per cent in favor of the welded joint.

* "An Electrically Welded Freight Car," by J. A. Osborne, p. 912.
† "Research in the Spot Welding of Heavy Plates," by W. L. Merrill, p. 919
‡ (See article on page 928).

The welded joint requires no expenditure of labor in laying off and punching the plates, in handling them between punch and riveter, or in heating and handling the rivets.

The welded joint requires no material in the form of rivets and this saving amounts to a considerable weight. Furthermore, a welded joint does not require that the plates shall be lapped over each other so far as for a riveted joint. In the riveted joint, a considerable amount of metal must be left between the rivet holes and the edge of the plate, otherwise the joint will be weak on account of the danger of the rivets pulling out through the edge; whereas the spot welds can be made practically at the very edge of the plate, and the joint will be just as strong as though made at the middle of the plate. This saving in material means a decrease in total weight of the completed structure; and any feature which will lighten the dead weight without decreasing the strength is, of course, very desirable in shipbuilding.

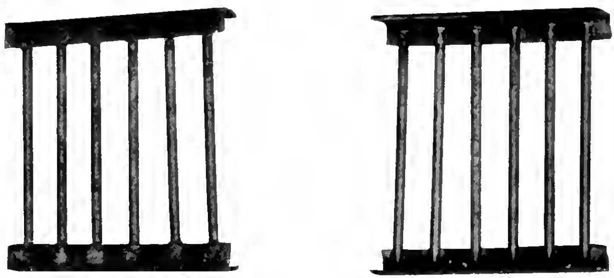


Fig. 1. Front and Back Views of Grating Constructed on Spot Welding Machine

Disadvantages of Spot Welding

There is no denying that the spot welder is inherently a heavy machine; but if we limit our comparison to the welder versus the bull riveter—and it is in replacing the bull riveter that the spot welder will find its most useful field—there is nothing to choose between the two machines.

The spot welder is inherently a single-phase machine, and in some cases power companies, particularly if their systems are of small capacity, will object to the unbalancing of their systems caused by the welder. However, if a number of welders are used they may be distributed among the various phases of a polyphase system, or a motor-generator set may be installed to take care of one or more machines. The actual cost of power per weld is small; in fact, under ordinary conditions, the saving in cost of rivets alone would pay for the power, and, assuming that the welder is worked at full capacity eight hours a day, would easily pay the investment charges on a motor-generator equipment if local conditions require its installation.

Field for the Spot Welder

It is stated above that the spot welder will find its chief field in replacing the bull riveter. Of course the ideal spot welder for shipyard use would be a machine which could be handled as easily as the pneumatic riveting tool, and which could be used in any place where the pneumatic riveter can be used. Unfortunately, this ideal is unattainable, at least with our present knowledge. Not only must we have contact between the electrodes and the plates on both sides of the joint, but the points of contact must be fairly accurately centered with respect to each other, and we must exert a heavy pressure, (as much as 20,000 or 30,000 lb. for plates ½ in. to ¾ in. thick) between the electrodes. In addition to this we must cause a current of 25,000 to 50,000 amperes to flow between the electrodes, which necessitates a transformer and heavy copper leads from it to the electrodes. On account of the heavy currents involved, the transformer must be mounted on the welding machine to minimize the length of the leads and consequently the reactive drop in them. These various requirements tend to make the spot welder for use on ship plates a rather heavy machine; and, if any attempt is made to weld the joint between plates after they are in place in the framework of a ship on the ways, adequate crane facilities must be provided for handling the welding machine. This is especially true since a welder for this particular work must have a throat at least deep enough to span a plate 5 ft. in width, which means that it must be strongly and consequently heavily built in order to obtain the requisite pressure between the electrodes.

In view of these conditions, it is evident that the immediate field of the spot welder is in the fabricating shop and in the yard, rather than on the shipways.

The spot welder is not, of course, limited merely to the joining of two flat plates. It can be used to advantage to weld an angle iron to a plate, a channel iron to a plate, a plate and two channel irons or angle irons, one on each side of the plate, or in fact almost any other combination of plates and structural members. A joint of three laminations of metal can be welded almost as easily as one of two, a little more power of course being required for the joint of three layers, on account of the greater amount of metal to be heated. In fact, if the welder is made of large enough capacity there seems to be almost no limit to the number of thicknesses of metal that can be welded at one time. The writer has welded as many as sixteen laminations, of $\frac{1}{16}$ in. thickness each, together at one operation, making perfect welds time after time.

It is evident from the foregoing that practically all of the rivets which are now driven in the shops and on the ground beside the ways can be advantageously replaced by spot welds. This really means doing away with quite a fair percentage of the rivets in the ship, with consequent saving in time, labor, and material, and a decrease in weight. All of the bulk heads can be fabricated by spot welding, all web frames and similar members, and in fact every structural part of the ship which is built up before being assembled in the ship itself.

There are numerous ways in which a spot welder can be used around a shipyard other than in fabricating the parts of a ship used in the hull construction. Consider, for instance, the manufacture of ladders and gratings. In the present method of building a ship ladder or grating, the side straps or supporting members are first laid off and punched for receiving the rungs. The rungs are accurately cut to length, not with a shear, but with a saw or miller, as the ends must be square; both ends of each rung must then be turned down for a certain distance from the end, leaving a shoulder to butt against the side straps. They are then assembled in the side straps and all the rung ends riveted over by hand labor to complete the ladder or grating.

Now the spot welder can be used to build up a ladder or grating of the same shape and

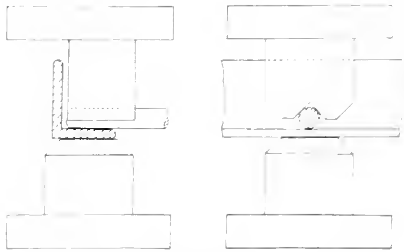


Fig. 2. Shape of Electrodes and Method of Placing Work in Them for Construction of Ladders and Gratings

appearance as the present standard type, butt-welding the end of each rung onto the side strap. But very special electrodes are required to get the heating effect at the proper place, and considerable care is required to get a good weld. However, by changing the design of the grating to adapt it to the welder, a welded grating can be made with a considerable saving in time and labor over the riveted grating. The results are shown in Fig. 1. Instead of a straight strap for the supporting frame, an angle iron is used, and a short length on each end of the rung is welded to one flange of the angle as shown. In making the weld the underside of this flange rests on a flat-topped electrode, while the rung is held in a V-shaped groove in the upper electrode. The shape of the electrodes used and the method of placing the work in them are shown diagrammatically in Fig. 2.

With this scheme the side straps do not require to be punched or drilled. The rungs, instead of being cut off squarely, and to an accurate length, and then turned down on the ends, are simply sheared off in a power shear, the ends do not need to be square, and a difference in length of $\frac{1}{4}$ in. or so does not matter, except possibly as it affects the appearance of the finished product. There is no riveting over of the ends of the rungs to be done. The actual time required for making a weld of this kind is from five to ten seconds and the power consumption, for ordinary work, is less than one tenth of a kilowatt-hour.

It is perfectly feasible to build a welder which would turn out ladders or gratings of this sort almost automatically. The welds at both ends of a rung would be made at the same time, both side angle irons being fed into the machine with the rungs properly placed on them by an automatic spacing

Fig. 3. Straight Rods Spot-welded to Angle Iron and then Bent by Hammer Blows, the Angle Being Supported only by the Unwelded Flange

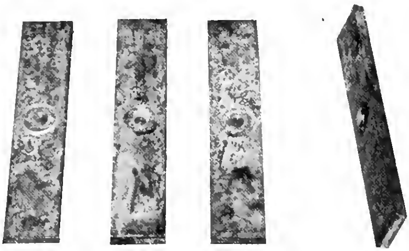


Fig. 4. Sample Plates with Holes Plugged by Spot-welding. At the right is shown a plate with plug in place previous to welding

apparatus. Such a machine should easily weld rungs in place at the rate of five a minute, and would require only one man to operate it.

That a ladder or grating built up as proposed above would be amply strong is illustrated by Fig. 3; a number of welds were made and the flange of the angle iron on which there were no welds was clamped in a vise. Then, by means of repeated blows from a heavy sledge hammer the rods were bent over as shown. This is a very severe test of the strength of the weld.

It sometimes happens that a hole will by mistake be punched in a plate where it is not needed. The spot welder can be used to plug such holes and make the plate as strong as, or stronger than, it was originally. It is first necessary to make a plug of the same material as the plate which will fit in the hole and which is slightly longer than the plate is thick. The length required will depend on the snugness of the fit of the plug in the hole; there should be enough metal in the plug to a little more than completely fill the hole. The plate is placed in the welder with the hole which is to be filled centered between the electrodes, the plug is placed in the hole, the electrodes brought together upon it, and upon the application of pressure and current the plug will soften, fill the hole, and weld to the plate.

Fig. 4 shows, at the extreme right, a piece of ½-in. plate with a punched hole which is to be plugged, and the plug in place previous to welding. The three pieces at the

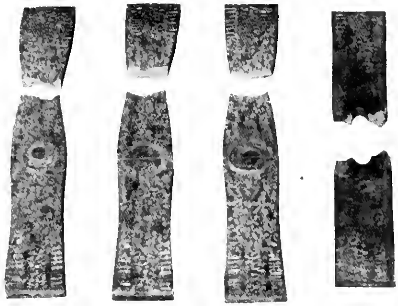


Fig. 5. Plates shown in Fig. 4, after Pulling in the Testing Machine. Note that all welded plates broke outside the weld

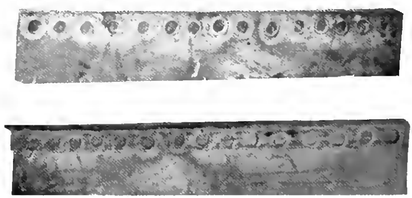


Fig. 6. Steel Plate Reinforced by Spot-welding an Angle Iron to It

left of the photograph have the plugs welded in place. A fact which the illustration does not bring out very clearly is that the surface, after the plug is fused in, is practically as smooth as the remainder of the plate, the maximum difference in thickness between the plugged portion and the remainder of the plate being not more than $\frac{1}{32}$ in. on a ½-in. plate.

That there is a real and complete weld between the plug and the plate is shown by

Fig. 5. The four samples illustrated in Fig. 1 were placed in a testing machine and broken by longitudinal pull, with the interesting result that not one of the three plugged plates broke through the weld. The sample at the right of the photograph was broken to give an indication of the strength of the samples after punching and before welding. Two samples (not shown) from the same bar but without the punched holes were pulled to find the original strength of the material. The results are given in Table I.

TABLE I

TENSILE TEST OF PLATES PLUGGED BY SPOT WELDING

No. of Sample	Description of Sample	Section In.	Tensile Strength Lb.	Location of Fracture
1	Punched $\frac{9}{16}$-in. diameter hole and plugged by welding	2 by ½	59,320	Outside weld
2	Punched $\frac{9}{16}$-in. diameter hole and plugged by welding	2 by ½	59,320	Outside weld
3	Punched $\frac{9}{16}$-in. diameter hole and plugged by welding	2 by ½	59,350	Outside weld
4	Punched $\frac{9}{16}$-in. diameter hole but not plugged	2 by ½	31,590	Through hole
5	Original bar, not punched	2 by ½	59,230	Through center
6	Original bar, not punched	2 by ½	59,000	Through center

It is interesting to note that the average of the breaking point of the three samples punched and plugged was 59,330 lb., whereas the average for the two samples not punched was 59,115 lb., or 115 lb. less. This proves that there was no weakening of the surrounding plate, due to the weld. That the ductility of the welded section was somewhat decreased is shown by the photographs of the samples after pulling.

The actual welding time required for plugging a hole in a plate is from five to ten seconds. Of course, it is necessary to have a plug of the proper size, but a variety of plugs, of all the standard rivet hole diameters and of lengths suitable for the various thicknesses of plates, could be made up and kept in stock in the yard. The method described should prove a valuable means of salvaging material which otherwise might have to be scrapped.

A simple variation of the welding of plates and structural shapes to form bulkheads and so forth is the welding of angle or channel reinforcing members to the plates around hatch coamings and other deck openings.

There is a field for the small spot welder in shipbuilding work, as well as for the heavy machine designed for work from ¼ in. to 1 in. in thickness. There are a large number of rivets in the smoke funnels of a ship, and in the ventilator cowls and pipes, all of which could be advantageously replaced by spot welds.

In the foregoing, it is shown that although the spot welder cannot, under present conditions, be advantageously used in the shipways to weld the outside plating of a ship into place, it still can be of a great deal of service in the shipyard. After it becomes firmly established in the yard, we may look for the construction of a shipway with crane facilities especially designed to handle the heavy welders, and such changes in the manner of building a ship as will allow the welder to be used to the fullest advantage. Such a radical step is some distance in the future, especially so on account of the well-known conservatism of the shipbuilding industry, but it is undoubtedly not only a possibility but a probability.

Some Recent Developments in Machines for Electric Spot Welding as a Substitute for Riveting

By J. M. Weed

Power and Mining Engineering Department, General Electric Company

The author's description of recent developments in machines for electric spot welding are very comprehensive. Evidently electric welders can be designed for use in all trades wherein metal is joined, with results superior to present methods. The author's experiments have demonstrated that the previously supposed natural limits of the process, as to thickness of the parts to be welded, are governed only by the capacity of the apparatus available for doing the work.—Editor.

Semi-portable Welders

It has been supposed in the past that the field of electric welding by the resistance process had certain natural limits as to the sizes of the parts which could be satisfactorily welded. Thus, in the case of spot welding, it was thought that the natural limit of the process as to thickness of the parts welded was about $\frac{3}{16}$ in. for each part, or a total thickness of $\frac{3}{8}$ in. Work done by the writer during the past winter in the development and use of an experimental machine of large capacity has proven conclusively that this supposed limit was due to the capacity of the apparatus which was available for doing the work. The experimental machine referred to, shown on page 919, has a welding current capacity of 100,000 amperes, and a pressure capacity of 75,000 lb. The maximum current at which it has been used is about 72,000 amperes, and the maximum pressure about 30,000 lb. The maximum thickness of material welded was three thicknesses of 1-in. plate. The design of the machines described in this article, which have been developed with particular reference to the substitution of electric welding for riveting in shipbuilding, was based upon the data and experience obtained with this experimental machine.

The machines to be described are two portable welders, one with 12-in. reach and the other with 27-in. reach, for use in the fabrication of structural parts, and one stationary machine with 6-ft. reach designed for welding two spots at the same time on large plates.

Portable Welders

A preliminary survey of the structural work in shipbuilding indicated that about 80 per cent of this work could be done by a machine of 12-in. reach, and that a 27-in. reach would include the other 20 per cent. Since both the weight of the machine and the kv-a. required for its operation are about 33 per cent greater for the 27-in. reach than for the 12-in., it seemed advisable to develop two machines rather than one with the longer reach.

These machines were to a certain obvious extent patterned after the riveting machines, illustrated in Fig. 1, which they are intending to replace. They are necessarily considerably heavier than the riveting machines, but like these they are provided with bales for crane suspension, for the purpose of carrying the machines around the assembled work or parts to be welded.

The maximum welding current available in these machines, with a steel plate enclosed to the full depth of the gap, is about 37,500 amperes, with the maximum applied voltage

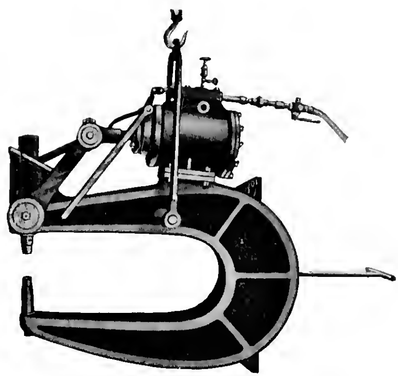


Fig. 1. A Standard Type of Pneumatic Riveter

of 534 volts at 60 cycles. Reduced voltages, giving smaller currents, are obtained in six equal steps, ranging from 534 down to 267 volts, from the taps of the regulating transformers which have been furnished with the machines.

This wide range of voltage and current was provided in order to meet the possible requirements for a considerable range in thickness of work, and for experimental purposes. Tests have shown, however, that the machines will operate satisfactorily on work of thicknesses over the range on which they are likely to be used when connected directly on a 440-volt, 60-cycle circuit, with no regulating transformers. Two plates 1/2 in. thick are welded together in spots from 1 in. to 1 1/4 in. in diameter, in from 12 to 15 seconds. Thicker plates require more time and thinner plates less time.

The welding current under these conditions is about 31,000 amperes; the primary current is about 600 amperes for the 12-in. machine and about 800 amperes for the 27-in. machine, the corresponding kv-a., at 440 volts, being 265 and 350 respectively.

Since the reactance of the welding circuit is large as compared with the resistance, the voltage necessary for a given current, and consequently the kv-a. necessary for the operation of the machine, is almost proportional to the frequency. Thus, these machines operate satisfactorily from a 25-cycle circuit at 220 volts, with the advantage that where the power-factor is from 30 to 40 per cent at 60 cycles, it is from 60 to 75 per cent at 25 cycles, and the kv-a. required at 25 cycles is about one half that required at 60 cycles.

The maximum mechanical pressure on the work for which those machines are designed is 25,000 lb. This is obtained from an 8-in. air cylinder, with an air pressure of 100 lb. per square inch, acting through a lever arm of 5 to 1 ratio. Lower pressures on the work are obtained with correspondingly reduced air pressures. A pressure-reducing valve is provided for this purpose, and also a pressure gauge for indicating the pressure on the machine side of the valve.

The pressure required to do satisfactory welding depends upon the thickness of the plates. It is necessary that the areas to be welded should at the start be brought into more intimate contact than the surrounding areas, in order that the current may be properly localized, and the heat generated in the region where it is needed. It is therefore necessary, on account of irregularities in the plate surface, that the pressure should be great enough to spring the cold plate sufficiently to overcome the irregularities. The pressure which will do this with heavy plates is ample for effecting the weld after the welding temperature is reached.

It should be explained in this connection that the rate of heating at the surfaces to be welded depends largely upon the contact resistance, and consequently upon the condition of the plates and the pressure used. If the plates are clean and bright, and the

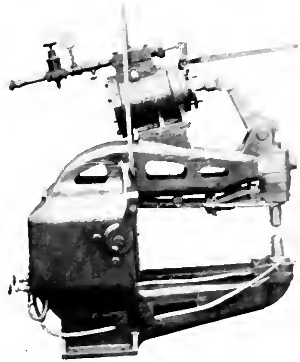


Fig. 2. Portable Electric Spot Welder with 27-in. Reach

pressure high, the rate of heating with a given amount of current is slow and the welding efficiency is poor. This makes it difficult to weld heavy plates if they are clean, since, as stated above, it is necessary to use large pressure with heavy plates to insure a better contact of the areas to be welded than that of surrounding areas. It is much easier to weld plates which carry the original coat of mill scale, or a fairly heavy coating of rust or dirt, affording a considerable resistance which is not sensitive to pressure. If this resistance is too great, the necessary current will not flow, of course, but if the scale is not too heavy it has little effect upon the current, the high reactance of the welding circuit giving it practically a constant current characteristic and making the rate of heating proportional to the resistance within certain limits. The scale melts at about the welding temperature of the steel, and is squeezed out by the high pressures used, permitting the clean surfaces of the steel to come together and effect a good weld.

A gauge pressure of about 70 lb., giving 17,500 lb. pressure upon the work, has been found to give good results under these conditions on 1/2-in. plates.

Both the mechanical pressure and the current are transmitted to the work in these machines through heavy copper blocks or welding electrodes. The shape of the tips of these electrodes is that of a very flat truncated cone.

The severity of the conditions to which the tips of the electrodes are subjected will be understood when it is considered that the

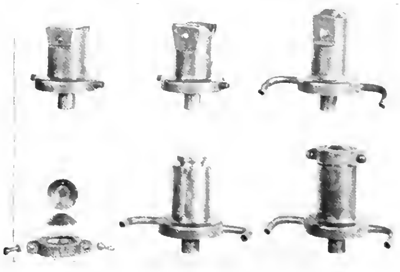


Fig. 3. Specially Designed Electrodes for Portable Welder

current density in the electrode material at this point is approximately 60,000 amperes per square inch, and that this material is in contact with the steel plates which are brought to the welding temperature, under pressures of 15,000 to 20,000 lb. per square inch. It must be remembered, also, that copper, which is the best material available for this purpose, softens at a temperature considerably lower than the welding temperature of steel. The difficulty of making the electrode tips stand up under the conditions to which they are subjected has, in fact, constituted the most serious problem which has been met in the development of these machines.

The shape of these electrodes gives them every possible advantage in freely conducting the current to and the heat away from the electrode tips, and in giving them the mechanical reinforcement of the cooler surrounding material. However, it has been found necessary to reduce, as far as possible, the heat generated at the tips of the electrodes by cleaning the rust and mill scale from the surfaces of the plates beneath the electrodes. The most convenient way which has been found for doing this is by means of a sand blast. The bodies of the electrodes are also internally water-cooled by a stream of water flowing continually through them. Still, after all of these things have been done, a gradual deformation of the tip of the electrode will occur, increasing its area of contact with the work, and thus reducing the current density in the work and the pressure density below the values needed for welding. This would make it necessary to change electrodes and to reshape the tips very frequently, and the total life of the electrodes would be short on account of the frequent dressings.

An effort has been made to overcome this difficulty by protecting the tip of the electrode by a thin copper cap, which may be quickly and cheaply replaced. As many as 160 welds have been made with a single copper cap, $\frac{1}{16}$ in. thick, before it became necessary to replace it. Unfortunately this does not entirely prevent the deformation of the electrode tip, but it stands up much better than it does without the cap.

Another method which has been tried for overcoming this trouble is by making the tip portion of the electrode removable, in the form of a disk or button, held in place by a clamp engaging in a neck or groove on the electrode body. While this protects the electrode body from deformation and wear, the tip itself does not stand up so well as does the combination of electrode and cap, where the tip of the electrode is not separated from the body.

Some electrodes have been prepared, but have not yet been tried, which combine the features of the removable tip and the cap. This will give the advantage of a permanent electrode body, and the removable tip with the protecting cap may stand up better than the unprotected tip.

Some of the electrodes which have been provided for these machines are shown in Fig. 3. The electrodes with flat top and with grooved top are for other work than spot welding, such as the welding together of bars and rods. These electrodes also have the thin protecting caps.

Some interesting features were introduced in the design of the transformers which are integral parts of these machines, owing to the necessity for small size and weight. Internal water cooling was adopted for the windings, which makes it possible to use current densities very much higher than those found in ordinary power transformers. The conductor for the primary windings is $^3/_8$ in. by $^1/_2$ in. copper tubing, which was obtained in standard lengths and annealed before winding by passing it through an oven which is used for annealing sheathed wire during the process of drawing. No difficulty was found in winding this tubing directly on the insulated core, the joints between lengths being made by brazing with silver solder. The entire winding consists of four layers of thirteen turns each in the 12-in. machine and three layers of thirteen turns each in the 27-in. machine.

The *U*-shaped single-turn secondaries were slipped over the outside of the primary windings in the assembly of the transformers. These were constructed of two copper plates each 3/8 in. thick and 6 3/8 in. wide, which were bent to the proper shape in the blacksmith shop, and assembled one inside the other with a 1/4-in. space between them. Narrow strips of copper were inserted between the plates along the edges, and the plates were brazed to these strips, thus making a water-tight chamber or passage for the circulation of the cooling water.

At 31,000 amperes, the current density in these secondaries is about 6,200 amperes per square inch, the corresponding densities in the primary windings being about 7,000 for the 12-in. and 9,000 for the 27-in. machine.

In case these machines are started up without the cooling water having been turned on, the temperature rise in these windings will be rapid, and in order to avoid the danger of burning the insulation, asbestos and mica have been used. The copper tubing was taped with asbestos tape, and alternate layers of sheet asbestos and mica pads were used between layers of the primary winding, and between primary and secondary and between primary and core. Space blocks of asbestos lumber, which is a compound of asbestos and Portland cement, were used at the ends of the core and at the ends of the winding layers. The complete transformer, after assembly, was impregnated with bakelite. The result is a solid mechanical unit which will not be injured by temperatures not exceeding 150 deg. C. Several welds could be made without turning on the cooling water before this temperature would be reached.

The transformers are mounted in a chamber in the body of the frame. The long end of the U-shaped secondary runs out along the arm of the frame and bolts directly to the copper base upon which the bottom electrode is mounted. The short end connects to the base of the top electrode through flexible leads of laminated copper, to permit of the necessary motion for engaging the work.

The copper bases upon which the electrodes are mounted are insulated from the frame by a layer of mica, the bolts which hold them in place being also insulated by mica.

The cooling water for these machines is divided into two parallel paths, one being through the primary winding, and the other through the secondary and the electrodes in series. Separate valves are supplied for independent adjustment of the flow in the two paths. The resistance of ordinary hydrant water is sufficiently great as to cause no

Fig. 4. Samples of Work performed by Portable Welder

concern regarding the grounding or short-circuiting of the windings through the cooling water, although it is necessary to use rubber tubing or hose for leading it in and out.

Some sample welds made on these machines are shown in Figs. 4 and 5. In Fig. 4 are shown some pieces of 1/2-in. by 2-in. machine steel which were welded in seven seconds with a current of 33,000 amperes. They were afterward clamped in a vise and hammered into the shapes shown in the photograph. The small pieces shown are sections which were sheared from the seam where two 1/2-in. plates had been welded together in a row of spots. The pieces of the plates were then split apart with a cold chisel in one case, and an effort was made to do so in the other, with the result that one piece of plate broke at the welds, as shown, before the welds would themselves break. Such tests as these show that the welds are at least as strong as the material on which the welds were made. Some samples of the 1/2-in. by 2-in. stock welded together in the same manner as those shown in this photograph were tested by bending in an edgewise direction, thus subjecting the welds to a shearing torque. The ultimate strength calculated from these tests was in the neighborhood of 65,000 lb. per sq. in. These tests showed also a very tough weld, the deflection being almost 45 degrees in some cases before the final rupture occurred. The maximum load occurred with a deflection of from 3 to 5 degrees, with a very gradual reduction in the load from this time till the final rupture.

Fig. 5 shows some welds made between pieces of machine steel 1¾ in. by 1¾ in. square. The current for these welds was 40,000 amperes, obtained with 535 volts applied. The air pressure as shown by the gauge for the sample at the left was only

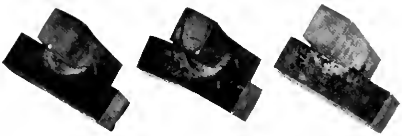


Fig. 5. Samples of Work performed by Portable Welder

25 lb., giving 6000 lb. on the work, while that for the other two samples was 70 lb., giving 17,500 lb. on the work. The sample at the left, if broken apart, would prove to be a poor weld, as one would judge from its appearance. The time of welding was 40 seconds for the middle sample, and 30 seconds for each of the others.

The equipment is provided with panels carrying contactors and selector switches for connecting the welding machine to the various taps on the regulating transformer.

Duplex Welder

This machine was developed for the application of electric welding as a substitute for riveting on parts of the ship composed of large sized plates, which may be fabricated before they are assembled in the ship. The specification to which it was built stated that it should have a 6-ft. reach and should be capable of welding together two plates ¾ in. thick in two spots at the same time. A machine capable of doing this work, with a 6-ft. gap, is necessarily so heavy as to preclude even semi-portability, and no effort was made in this direction.

With the welding circuit enclosing a 6-ft. gap, and carrying the very heavy current necessary to weld ¾-in. plates, the kv-a. required would be very large. A great reduction in the kv-a. and at the same time a doubling of the work done, is obtained in this machine by the use of two transformers as integral parts of the machine, and two pairs of electrodes, thus providing for the welding of two spots at the same time. The transformers are mounted in the frame of the machine, on opposite sides of the work, and as near to the welding electrodes as possible, so as to obtain the minimum reactance in the welding circuit. The polarity of the electrodes on one side of the work is the reverse of that of the opposed electrodes, thus giving a series arrangement of the transformer secondaries, the current from each transformer flowing through both of the spots to be welded.

The bottom electrodes are stationary, and the copper bases which bear them are connected rigidly to the terminals of their transformer, while the bases which carry the top electrodes are connected through flexible leads of laminated copper, to permit of the motion necessary for engaging the work.

Previous tests with the experimental machine, page 919, had shown that, to successfully weld two spots at the same time in the manner adopted here, it is necessary that the pressures shall be independently applied. Otherwise, due to inequalities in the thickness of the work, or in the wear and tear of the electrodes, the pressure may be much greater on one of the spots than on the other. This results in unequal heating in the two spots. The resistance and its heating effect are less in the spot with the greater pressure. The two top electrodes in this machine were therefore mounted on separate plungers, operated by separate pistons through independent levers.

The pressures obtained in this machine with an air pressure of 100 lb. per sq. in., are 30,000 lb. on each spot, giving a total pressure of 60,000 lb. which must be exerted by the frame around the 6-ft. gap. The necessary strength is obtained by constructing the frame of two steel plates, each 2 in. thick, properly spaced and rigidly bolted together.

The use of steel in this case is easily permissible on account of the restricted area of the welding circuit and its relative position, resulting in small tendency for magnetic flux to enter the frame. However, the heads carrying the electrodes, being in close proximity to the welding circuit, were made of gun metal.

The two air cylinders are mounted on a cast-iron bedplate in the back part of the machine. The levers connecting the pistons to the electrode plungers, which are 7 ft. in length, were made of cast steel, in order to obtain the necessary strength.

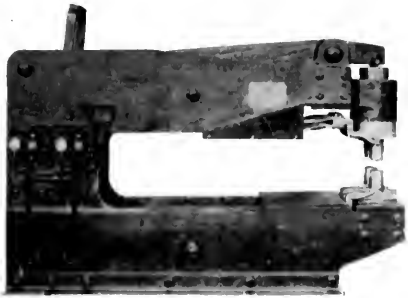
The maximum welding current for which this machine was designed is 50,000 amperes. This current is obtained with 500 volts at 60 cycles applied.

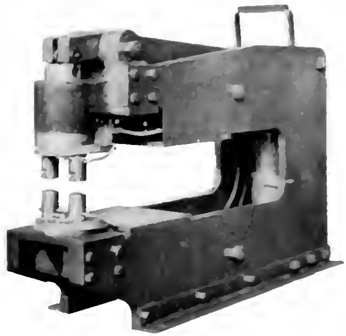
Sample welds made with this current on ⅝-in. boiler plates are shown in Fig. 8. A comparison of the two pairs of plates is of interest as showing the effect of the mill scale on the surfaces to be welded. All of these sample plates had been cleaned by a sand blast on one side only, the other side being just as it came from the yard. In welding the pair of plates shown on the right in this photograph, the clean sides of the plates were placed together, while for the pair on the left the scale sides were placed together. The length of time consumed in welding was the same for corresponding welds in both pairs of plates, the time in seconds being indicated by the numbers on one of the plates. Both pairs of plates were split apart by means of a cold chisel under the steam hammer. While the right-hand pair separated quite easily along the original cleavage surface, showing that no proper welds but only adhesions had been made, the appearance of the left-hand pair leaves no question as to the satisfactory character of these welds.

through the individual plates, entering and leaving on the same side. This current does not produce heat at the point where it is needed, and it is therefore wasted. The proportion of the total current which is wasted in this manner depends upon the distance between the pairs of electrode tips. This distance for these welds was 8 in., center to center.

The distance between the electrode bodies for this machine is fixed at 8 in., center to center, but the distances between the centers of the tips may be easily varied from 6 in. to 10 in. by shifting the tip from the center of the body toward one side or the other.

Provision has been made for shifting the electrodes on their bases to positions 90 degrees from those shown in the pictures, thus spacing the welds in a direction along





Figs. 6 and 7. Views of Duplex Electric Welder having a Reach of 6 ft. Welds two spots at a time

The size of the weld is seen to increase with the time, the diameter of the welded spot being about $1\frac{1}{4}$ in. for the pair of welds made in 25 seconds, and about $1\frac{3}{4}$ in. for those made in 35 seconds. In other respects there seems to be no particular difference in these welds.

Special attention should be called to the middle one of the three 35-second welds. While the other welds were made in pairs, this one was made alone, the other pair of electrodes having been short-circuited. It will be seen that the diameter of this weld is greater than the diameter of those welded the same length of time, but in pairs. The explanation for this is that when a pair of welds is made, some of the current, instead of passing directly through both plates across the surfaces to be welded, is shunted across

the axis of the machine instead of transverse to it.

One of the transformers in this machine is shown in Fig. 9. These transformers are insulated and cooled in the same manner as those in the semi-portable machines. The windings are interlaced in order to obtain minimum reactance, the primary being wound in two layers of 11 turns each, one inside and the other outside of the single turn secondary.

With 50,000 amperes in the secondaries of these transformers the current in the primary is 1800. The respective current densities are 7000 and 9000 amperes per square inch. The kv-a entering the transformers on this basis, the two primaries being in series on 500 volts, is 450 for each transformer.

These are probably the smallest transformers ever built for so large a rating, the over-all dimensions, exclusive of terminals, being 11 in. by 16 in. by 18 in.

This machine also has been provided with a regulating transformer for applying different voltages to give different values of welding current, and with a panel carrying the necessary selector switches and contactor. The maximum voltage provided by this regulating transformer as at present constructed is 440. If it is found that the current obtained with this voltage is not sufficient for the heaviest work which it is desired to do with this machine, the maximum voltage will be changed to 500.

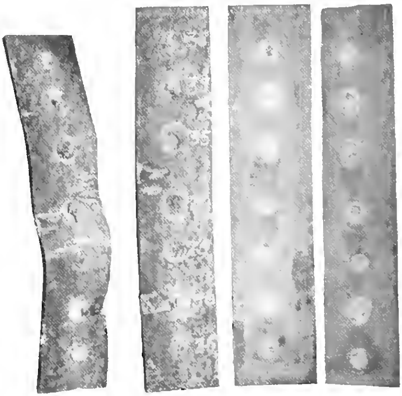


Fig. 8. Samples of Welds performed on Duplex Welder

The kv-a. entering the transformers at 440 volts will be approximately 350 each, instead of 450.

In order that this machine may be operated from any ordinary power circuit, it will be necessary to use a motor-generator set provided with a suitable flywheel. This will eliminate the bad power-factor, distribute the load equally on the three phases, and over a much larger interval of time for each weld, thus substituting small gradual changes in power for large and sudden changes. On account of the high reactance the welding current will remain practically constant as the speed of the motor-generator set falls away, thus favoring the utilization of the flywheel. The total maximum power drawn from the circuit with this arrangement would be about 100 kilowatts.

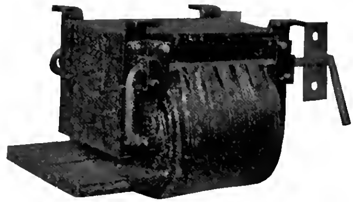


Fig. 9. One of Two Transformers supplied with Duplex Welder

Transformers for Electric Welding

By W. S. Moody

Engineer, Transformer Department, General Electric Company

Transformers for electric welding fall into two distinct classes, those for spot welding and [illegible] arc welding. The main requirements of the first type are the ability to carry exceedingly large currents [illegible] from 50,000 to 75,000 amperes, and a compact construction owing to the fact that the transformer [illegible] an integral part of the welding machine. The very large currents necessary for [illegible] and the resultant heating require some artificial means of cooling the windings, and water circulation through [illegible] is the means generally employed. The arc welding transformer is required to supply a constant current varying from 60 to 250 amperes and an open circuit voltage of from 100 to 150. Some means [illegible] provided for changing the current supply to meet the requirements of the work. Mr. Moody enumerates the essential requirements of each type of transformer and describes the construction of [illegible] requirements. —Editor.

Electric welding, especially by the Thomson process and its various modifications, is by no means a new art, and suitable transformers for the purpose were developed many years ago. In the development of such transformers, by Professor Thomson, Herman Lemp, and the writer, more than twenty five years ago, it was necessary to solve many problems that had not been previously solved in connection with transformers for electric lighting, because these welding transformers were far larger in capacity and had to deliver currents enormously greater than had ever been previously used for commercial purposes. While, therefore, there is not anything radically new needed to supply the recently greatly augmented demand for transformers for electric welding, a general presentation of the desirable characteristics of such transformers will, I trust, be timely in connection with this issue of the General Electric Review.

Transformer design in general consists of balancing diametrically opposing characteristics, the proper balance of characteristics for any particular case depending upon the class of service for which the transformer is to be used. Transformers for welding differ essentially from other types and are not subject to the same limitations as ordinary lighting and power transformers. For example, one of the essential requirements for welding transformers (particularly for spot welding) is compactness, while for lighting and power transformers high efficiency, low exciting current, and good regulation are essential. These characteristics are diametrically opposed to each other. The requirements which must be met will be outlined in detail under the two general headings of transformers for spot welding and arc welding.

Transformers for Spot Welding

Spot welding is the process by means of which two or more thicknesses of metal are welded together at spots, this being accomplished by placing electrodes on opposite sides of the pieces to be welded together and forcing current through the metal from one electrode to the other, thereby raising the metal to the welding temperature and obtaining a cylinder of homogeneous metal between the electrodes. It is used as a substitute for riveting or bolting and in some cases for arc welding. For a number of years it has been used quite extensively for welding thin plates together, but at the present time there is an increasing demand for outfits for welding heavier plates from $\frac{1}{4}$ in. to 1 in. thick.

The essential requirements of transformers for this purpose are:

1. Very large currents at low voltages, the currents running as high as 50,000 or 75,000 amperes, and the voltages between 4 and 15.

2. If different classes or thicknesses of metal are to be welded by the same outfit, it is necessary to provide for variation in the voltage in order to obtain suitable current for the different classes of work.

3. On account of the high current it is necessary to have the transformers as near to the work as possible in order to avoid excessive cost of low voltage bus bars. This requirement practically means that the transformer must be an integral part of the welding machine, and it is therefore necessary that it be as compact as possible.

4. The fact that the transformer is an integral part of the welding machine and has such may be subject to very rough usage in factories, blacksmith shops, [illegible] or even exposed to the weather, necessitates particularly rugged construction. The fire risk and mechanical features make it desirable [illegible] and the insulating materials must be of a durable character [illegible] relatively high temperatures.

5. There must be no danger [illegible] shock [illegible] of the [illegible] currents.

Even with these [illegible] ments, transformers [illegible] are very satisfactory in their operation and stand up under the most adverse operating conditions. While merely enumerating the requirements will in many cases suggest the logical design, the important features of the construction will be briefly pointed out.

Construction

The requirement of compactness necessitates working the material at very high current and flux densities, with the consequent high losses and temperatures; but since the transformer operates only intermittently, usually being disconnected from the circuit considerably more than 50 per cent of the time, the maximum temperature is momentary, and the standard rules of heating for apparatus operating under continuous load may be modified. It is therefore permissible for the transformer winding to reach a maximum temperature greater than in other electrical apparatus. The insulation must therefore be designed to withstand relatively higher temperatures.

Small units up to 100 kv-a. instantaneous rating may, in general, be satisfactorily cooled by natural circulation of air, but on larger units it will sometimes be necessary to resort to artificial cooling. For heavy work it is usually necessary to water-cool the electrodes in order to prevent their reaching too high temperatures, and it is in just such cases, since large transformers are required, that artificial cooling of the transformer itself is necessary.

With the water-cooled electrodes no further complications, so far as the operation of the outfit is concerned, are incurred by water-cooling the transformer windings. The most effective way to cool a winding is to wind the primary coils of copper tubing and circulate water through these tubes. There is no objection to circulating water through the primary winding, even where the voltage is as high as 550.

By carefully insulating, thermally, the secondary winding from the primary by means of heat-resisting material, it is permissible to operate the secondary at a relatively much higher temperature than the primary, and in most cases artificial cooling of the secondary can be entirely eliminated, except at the electrodes. When additional cooling is needed, since copper is such a good conductor of heat, it will be frequently possible to cool the secondary coils satisfactorily by applying water locally to the parts of the coils which project beyond the primary windings.

Where necessary to use internal cooling of the secondary coils and where the cross section is much greater than could be obtained satisfactorily by copper pipe, an excellent method is to use an auxiliary coil of copper tube brazed around the heavy conductor proper, water being circulated through this copper tube.

Due to the probability of careless handling, especially when water cooling is used, the insulation between the primary and secondary and on all primary leads and terminals must be very carefully designed for the safety of the operator. As has been pointed out, the high operating temperatures require special heat-resisting insulation, and in general this will also fulfill the electrical requirements. Due precaution must, of course, be made to obtain a rugged design and one that will withstand the general practices of the forge shop rather than an electrical installation.

Line Welding

In principle, line welding does not differ materially from spot welding, and the requirements of the transformers are substantially the same. In this case two or more plates are welded together, a continuous weld being made. One electrode is continuous for the entire length of the weld and the other electrode consists of a copper disk or wheel which rolls along the seam to be welded. Such welding, however, is usually applied only to thin sheets and the current required is relatively small, while the interval during which the transformer is required to deliver current depends on the length of weld to be made. In certain cases an interrupter is used which further reduces the time the current is on, giving a series of overlapping spot welds.

Electric Heating

Heavy current may be used to electrically heat steel bars or angles for a few inches of their total length so that they may be bent or formed into suitable shapes. Longer sections of steel may be heated electrically for hardening, but in the two foregoing cases the essential transformer requirements are similar to the requirements for spot welding.

TRANSFORMERS FOR ARC WELDING

Arc welding is the process of joining two pieces of metal together by fusing the joint with the aid of the electric arc. The metal to be welded usually forms one electrode and a small pencil of carbon or metal forms the other. The pencil electrode is moved along the seam in such a way as to deposit the molten metal at the joint. This process has been long used in a limited way; direct current, however, being considered necessary for a satisfactory weld. The recent demands for welding in connection with shipbuilding started experiments which have demonstrated that alternating current produces equally satisfactory results to direct current for this form of welding.

The principal requirements of transformers for this process may be tabulated as follows:

1. The arc requires a constant current of a value which differs with the type of work or thickness of the stock, from about 60 to 250 amperes, and the open circuit voltage should be at least 100, and may run up to 150.

2. Taps or adjustable inherent reactance are required for changing the current with the requirements of the work.

3. To obviate the use of long secondary leads of heavy copper it is necessary to have the transformer near the work, and in many cases this will mean that it must be easily portable. For this purpose the transformer should preferably be air cooled, of light weight, and of such rugged construction that it will stand rough handling and the lack of care which ordinarily go with installation in a tank shop or shipyard.

4. The transformer must be foolproof. There must be absolutely no danger from electrical shocks in handling the transformer or any of the accessible circuits. This is specially necessary, since the men who handle the apparatus will in most cases be without electrical knowledge.

Construction

While the transformer for arc welding will not be of such a radical design as that required for spot welding, the requirements mentioned call for considerable departure from the ordinary power or lighting transformer.

The necessity for constant current under the varying conditions of the arc requires some way of changing the constant potential of the ordinary supply. This may be done by an inductance or capacity in series with the arc, of such a value that the current variation is kept within the desired limit. These methods are in use and have certain advantages, yet a cheaper and more compact arrangement consists in using a transformer having a high inherent reactance. The reactance will be of the order of 95 per cent. In the simplest design current is varied by means of taps in the primary or secondary winding, and the corresponding current variation is of necessity step by step. Transformers in which the inherent reactance is varied mechanically by moving one winding with respect to the other permit a continuous and gradual change in the arc current, and are therefore simple and more flexible in operation.

In many cases insurance rates make it inadvisable to use oil for cooling, and air-cooled units are essential. As with spot welding, the current is not on continuously, and correspondingly high losses are permissible.

No general rule can be made for all conditions, yet where light weight and portability are important, the permissible temperature rise of the transformer will be high and insulation must be used which will not be affected by the high temperatures. It is also important that the windings be well impregnated with heat-resisting material. This will help to form the coils into rugged units well suited to the unsatisfactory operating conditions.

The Series System

Where a number of arcs are to be used within a reasonable distance of each other the series system may be used. In this arrangement the secondary of an ordinary constant current transformer supplies current to the primary of all the welding transformers in series. The individual transformers insulate the welding apparatus from the series circuit and transform from the series current to current of proper value for the arc. In this case the inherent reactance of the series transformer is low, but other features of the design are the same as those discussed above. The power factor of such a system can be safely made much higher than where individual arcs are operated in multiple from constant potential circuits.

The Constant-energy Arc-welding Set

By P. O. Noble

Direct-current Engineering Department, General Electric Company

The author describes a new and ingenious type of arc-welding equipment which combines those characteristics best suited to perform this kind of welding. As pointed out frequently in this issue, the success of electric arc welding is largely dependent upon the skill of the operator. The control of the location of the crater can best be effected by the use of a short arc, and the advantage of the system described lies in the fact that it facilitates the maintenance of a short arc and makes it difficult to continue a long one.—Editor.

As a result of much research work, there has been completed the development of an ingenious type of arc-welding equipment which combines high efficiency, light weight, and the electrical characteristics best suited for the arc.

There are many opinions as to what are the proper characteristics for the machine which is to furnish the power to be used in electric arc welding. However, all will agree that the ideal condition for a homogeneous weld on a given piece of work is obtained when the voltage and the current at the arc are constant. This is a condition which is impossible to obtain with the manually controlled arc, and the question arises as to whether the current should be held constant with varying length of arc or whether the total energy should remain constant.

The balancer set described in this article delivers practically constant energy to the arc, and it will be shown herein that this is the proper characteristic.

Exhaustive tests have proven conclusively that the success of electric arc welding is largely dependent upon the skill of the operator. In order to secure union between the deposited metal and the metal of the work, it is necessary that the "crater" be established *in the work* and not in the deposited metal; and the skill of an operator may be judged by his ability to establish this crater at the proper place.

The control of the location of the crater can be effected by the use of a short arc, but this control cannot be obtained when a long arc is used. The use of a long arc, makes it possible to fill the space between two plates with deposited metal so as to have the appearance of a good weld, which upon being broken open will be found to be entirely separate from the plate, being in the condition of molten metal poured in and immediately chilled. It is an unfortunate fact that if the average operator is welding from a supply source which will maintain a long arc, he will unconsciously hold a long arc on account of the greater ease of manipulation.

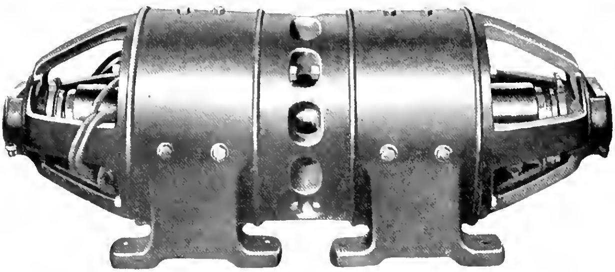


Fig. 1. 3-kw., 1700-r.p.m., 125 60 20-volt Compound-wound Balancer Type Arc-welding Set

The principal advantage of the constant-energy system lies in the fact that it facilitates the maintenance of a short arc and makes it difficult to maintain a long arc.

The rate of consumption of electrode material is proportional to the current in the arc and is independent of the voltage across the arc. In the constant-energy system, when the operator shortens the arc, the current increases and the rate of wire consumption increases, thereby tending to bring the arc length back to normal. If he lengthens the arc, the current decreases and the rate of wire consumption decreases. This automatic action tends to maintain the arc at the proper length. If the arc is unduly lengthened, the current will decrease until the electrode does not fuse properly and the arc will go out.

In the constant-current system, the rate of wire consumption is constant and there is no such corrective effect as just described. This system also makes possible the maintenance of a long arc with the consequent deposition of a large amount of highly oxidized and porous metal. The oxidization is evidenced by the fact that with a long arc there is present, in addition to the black oxide of iron (Fe_3O_4) which is present on all bare wire welds, an abundance of red oxide of iron (Fe_2O_3) showing that the metal is more highly oxidized in passing through the arc.

The excess of energy in a long arc must be consumed in heating the metal in the arc stream, as elaborate tests have shown that the wire consumption, and therefore the energy at the terminal, is proportional to the current and is not affected by the length of the arc.

The constant-energy balancer set consists of a direct-current motor mechanically connected to a direct-current generator. The construction of the set is shown in Fig. 1, the control panel is shown in Fig. 2, and the electrical connections of the set and panel are shown in Fig. 3.

Fig. 2. CR 4907-A Arc-welding Panel

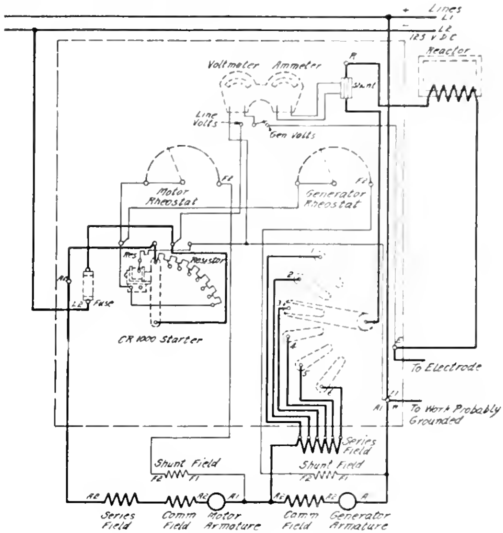


Fig. 3.

It will be seen that the motor and generator are electrically connected in series across a supply circuit of constant potential, this potential having the ordinary commercial value of 125 volts. This arrangement is of considerable advantage, as it makes possible the use of generator equipment which is standard for other purposes. It also results in a marked saving in the cost of the copper necessary for the transmission of power.

One terminal of the welding circuit is taken from the connection between the two armatures, and the other terminal from the positive line. The polarity of the motor and generator is such that the armature currents of the two machines add together in the welding circuit, thereby making possible an approximate 50 per cent reduction in the size of the units involved. No series resistance is used in the motor, generator, or welding circuits, the difference between the supply voltage and the arc voltage being absorbed by the motor. This results in saving the power which is usually wasted in rheostats.

The ratio of the energy at the arc to the input to the set is 56 per cent. With the ordinary set of corresponding capacity, using series regulating resistance, this ratio is approximately 22 per cent. The saving in power resulting from this gain in efficiency is a feature of great importance.

The initial voltage for striking the arc, and the average current for the operation at hand may be regulated at the desire of the operator by means of the motor and generator field rheostats, and by means of the dial switch which changes the number of effective turns in the differential series-field winding of the generator. Changes of current may be obtained by very small increments from 40 to 150 amperes.

After the arc is established, the variations in current and voltage at the arc with change in the relative position of electrode and work follow approximately the Constant Energy Law.

This regulation is entirely inherent in the set itself, being accomplished without the use of energy-consuming resistors or vibrating regulators.

Figs. 4, 5, and 6 show oscillograph records of current and voltage at the arc on various types of equipment.

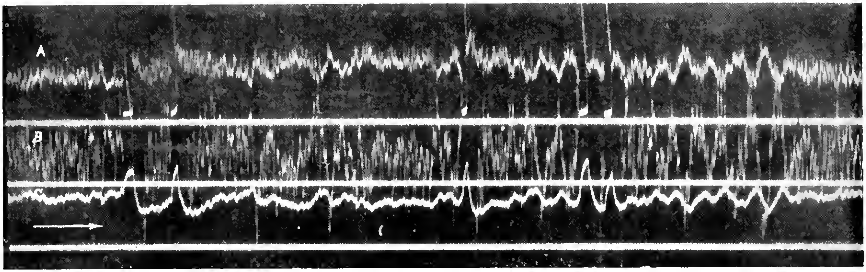


Fig. 4. Constant Potential System with Automatic Current Regulator and Variable Series Resistor
Curve A—Voltage across welding arc. Curve B—Voltage across control magnet. Curve C—Current in Arc

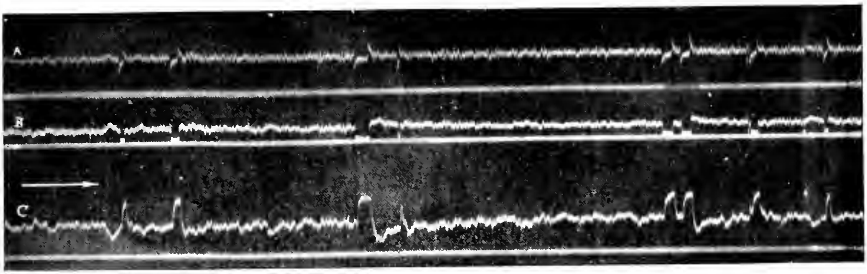


Fig. 5. Constant Potential System with Fixed Series Resistor
Curve A—Voltage across generator. Curve B—Voltage across welding arc. Curve C—Current in arc

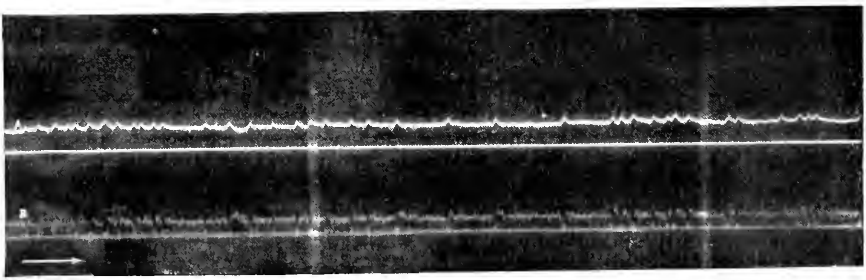


Fig. 6. Constant Energy Arc-welding Equipment (G-E Balancer)
Curve A—Current in arc. Curve B—Voltage across arc

The Metallurgy of the Arc Weld

By W. E. Ruder

Research Laboratory, General Electric Company

The microscope has played an important part in the study of the internal structure of steels and other metals. However, the mere inspection of a few photomicrographs by the untrained eye will reveal nothing of value; it is only through an intelligent study of these magnified structures in conjunction with the test performances of the sample that any useful knowledge can be derived from microphotographs of specimens of unknown properties. It is only natural to find that the microscope has given us considerable information respecting the character of electric arc welds, and of the factors that are responsible for successful and unsuccessful results. The factors that have an important bearing on electric welds as revealed by the intelligent use of the microscope are given in this article.—Editor.

We have learned to know, with a fair degree of certainty, what a steel casting should be to be acceptable for any given engineering purpose, and we are apt to be very particular about such a casting when human life would be endangered by its failure in service. This is true of all steel or iron parts which go so largely into the make-up of our present-day necessities.

In building up and bringing together many scattered facts about the behavior of iron and its alloys, under varying conditions, the microscope has played a very important rôle. It satisfies the natural curiosity to "see what's going on." Merely to see a line of signal flags on a destroyer, however, does not help us much unless we know what the signals mean. Just so the intelligent investigation of a metallurgical product like a weld made by an electric arc involves considerably more than a mere examination of the metal or its fracture under the microscope, much as this may reveal.

The making of a good weld is essentially a metallurgical problem. More specifically, an arc weld is a steel casting made by a continuous process both as to melting and casting. What we require is a sound, fine-grained casting, free from blowholes and slag inclusions, and low in impurities. This casting must also make a continuous and perfect union with the plate or material to be welded.

The physical properties of a weld will depend upon five distinct factors, namely: (1) crystal structure, (2) gas holes, (3) slag inclusions, (4) impurities, and (5) composition. These factors are identical with those determining the properties of any steel product, with the exception that most of the latter may be improved by heat treatment or working, while in the large majority of cases the weld must be used substantially as made. The order in which these factors is given is not to be taken as the order of their importance. The time has not yet arrived when such an order can be set down.

Crystal Structure

In studying the crystal structure of a large number of welds as revealed by the fracture, it appears that a very fine grain is produced by depositing the metal rapidly in comparatively thin layers, thus preventing the plate from heating up sufficiently to slow down the cooling. As soon as this occurs, columnar crystals begin to form with their resulting brittleness. It is often desirable for other reasons, however, to maintain as large a molten pool as possible. In such a case the only recourse to maintain a fine structure is to hammer the weld while still hot to prevent the formation of too coarse a structure. The cooling effect of the plate upon the weld structure may be readily observed in running a short length of weld across a plate. The first part of the weld will show a fine-grained fracture, while a little further along a decided growth begins, gradually changing to an entirely coarse structure as the plate heats up. Methods of keeping the plate cool with a stream of water have been tried with considerable success as far as the grain size is concerned, but difficulties of manipulation have prevented its adoption in practice.

Gas Holes

Gas holes are to be found in all electric welds and are an important source of weakness. Their occurrence is frequently laid to the presence of dissolved gases or gas-forming impurities in the electrode material. This is undoubtedly true, but only to a limited extent. Dissolved or occluded gases in the electrode are largely liberated as the metal passes through the arc stream and cannot have any considerable effect upon the deposited metal. They do affect the working of the electrode, however, as they cause sputtering, frequently so bad as to make the electrode useless. Experiments have shown this to be particularly true of highly oxygenous electrode steel. Carbon is one of the worst offenders in producing gas holes. Always

Fig. 1. Slag Enclosed in Weld

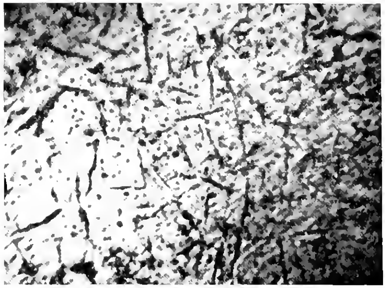


Fig. 2. Lines in Weld Annealed

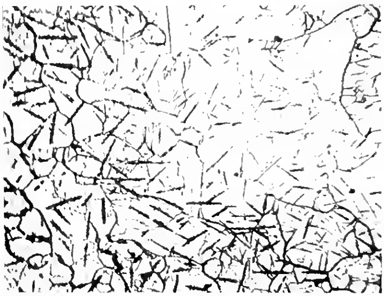


Fig. 3. Electrolytic Iron. Nitrogenized by annealing in NH_3 12 hrs. 750 deg. C.

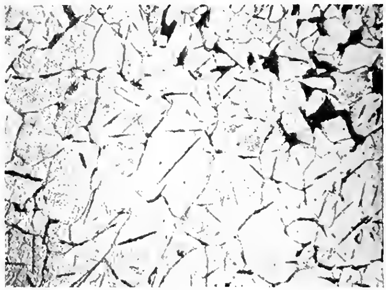


Fig. 4. Electrolytic Iron. Nitrogenized by annealing in NH_3 12 hrs. 750 deg. C., but subsequently annealed in vacuum for 2 hrs. at 1000 deg. C. Areas smaller and lines diminished in number

Fig. 5. Same as Fig. 3 showing Areas at High Magnification

Fig. 5a. Nitride Areas in Electrolytic Iron Treated as in Fig. 3

ready to combine with oxygen, it finds a rich supply in the metal deposited by the arc. Carbon monoxide is formed and, owing to the rapid solidification of the metal, is trapped. The carbon in the plate also becomes an important factor in this connection. The carbon in that portion of the plate dissolved into the welding pool reacts with the large percentage of iron oxide contained therein and forms more carbon monoxide which, being farthest away from the weld surface and nearest the cooling medium, has no opportunity to escape. Welds made on carbon-free iron with a carbon-free electrode showed only an occasional small gas hole, while it is a matter of common knowledge that steels containing only 0.3 per cent carbon are often very difficult to weld.

In this connection, the gaseous content of the plate is probably an important cause of gas holes in the weld, as yet not sufficiently investigated. It is more than probable, however, that if the plate contains considerable amounts of gases which are liberated on heating to fusion, these will affect adversely the quality of the weld.

Slag Inclusions

Slag inclusions are a common source of weakness in welds, particularly where covered electrodes are used. Slag inclusions are a common source of weakness in welds, particularly where covered electrodes are used by inexperienced workmen. Unless carefully handled, the slag becomes entangled in the deposited metal and does not have time to properly rise to the surface. The slag does aid in preventing the oxidation of the surface of the pool and thus limiting the amount of dissolved oxygen in the weld. The slag inclusions caused by the presence of manganese sulfid, silica, and the like, are of minor importance, as the areas affected are small. In using wrought iron welding wire, slag is frequently introduced from the electrode which may contain quite appreciable quantities.

Impurities

One of the most important factors, since the necessary property of ductility is so largely dependent upon it, is that of impurities found in the weld. All electric welds have a high oxygen content due to the highly oxidizing condition under which they are made. This oxygen content will not alone account for the lack of ductility. Microscopic examination reveals the presence in most welds of a large number of lines (Fig. 2) or plates which bear a close resemblance to those seen in iron which has been highly nitrogenized (Fig. 3). Nitrogen does not always appear in this particular form, as may be seen in Fig. 4, where the most highly nitrogenized sections show up as dark patches not unlike pearlite. These are shown under higher magnification in Figs. 5 and 5a. It may also appear as a cement between grains in such parts as contain the highest percentage of nitrogen. The needles or plates are merely one phase of the nitrogen-iron combination. In carbon steels they often do not occur at all, even when the nitrogen content is as high as 0.15 per cent. There is some indication that the nitrogen enters into combination with the iron and carbon, forming an iron-carbon-nitrogen compound. This, however, has not yet been definitely proven.

The needles or nitrogen lines are then merely an indication of the presence of a considerable percentage of nitrogen, but their absence does not always mean that nitrogen is not present. Strauss finds 0.12 per cent nitrogen in electric welds and 0.020 per cent in acetylene welds. Desch reports an analysis of an electric weld which contained ten times as much nitrogen as the plate.

Nitrogen is one of the most effective elements for making steel brittle. As little as 0.06 per cent will reduce the elongation on a 0.2 per cent carbon steel from 28 per cent to 5 per cent. It is contained in regular steel only in very small amounts, varying from 0.02 per cent in Bessemer steel to 0.005 per cent in open hearth. Under ordinary conditions of fusion, nitrogen has little effect upon iron, but under the conditions of the electric arc the nitrogen becomes much more active. This is probably due to the formation and decomposition of nitrogen-oxygen compounds with a consequent liberation of active atomic nitrogen. The fact that these lines do appear in welds made in nitrogen gas alone (Fig. 6) suggests that the oxygen need not be present, the nitrogen molecule being split up by the arc stream, or perhaps the iron vapor combines directly with the nitrogen. There is some evidence that it does.

The elimination of these nitrides and oxides must be accomplished before the weld can be made ductile. Many attempts have been made to do this by the alloying of various scavengers with the electrode material, or by painting them on, or in some way attaching

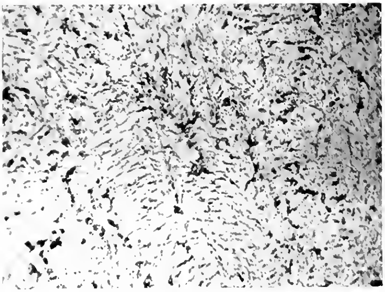


Fig. 6. Bare Wire Weld Made in Nitrogen Gas Close Annealed 750 deg. C

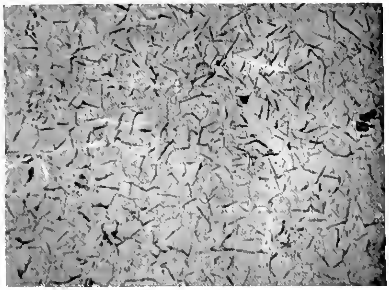


Fig. 7. Electrolytic Iron Electrode. Weld made in air. Annealed 750 deg. C.

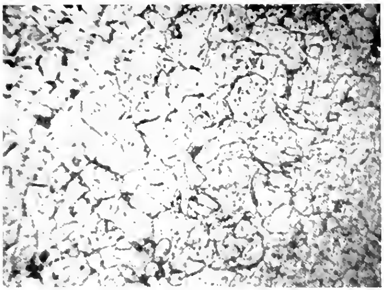


Fig. 8. Section of Weld Made with Pure Electrolytic Iron in Nitrogen Gas

Fig. 9. Section of Weld Made with Pure Electrolytic Iron in Hydrogen Gas

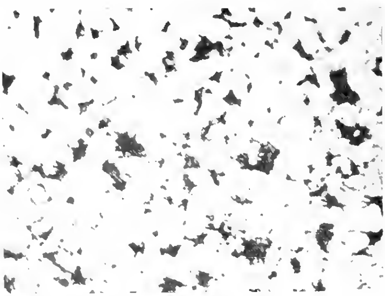


Fig. 10. Section of Weld Made with Pure Electrolytic Iron in CO_2 Gas

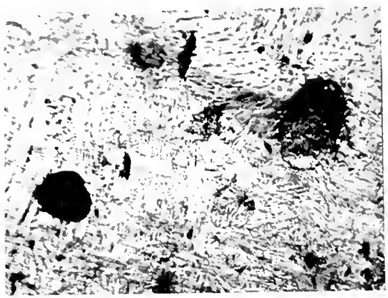


Fig. 11. Unannealed Weld Section. Weld made with covered electrode

them to the electrode. These have met with little success, chiefly because the very fact that they are deoxidizers or denitrogenizers means that their affinity for oxygen or nitrogen is greater than that of iron, so that their effectiveness is largely, if not wholly, destroyed in passing through the arc.

There are some metallographists who maintain that these markings herein termed nitrogen lines are not due to nitrogen but to carbide, martensite, or some internal strain phenomena. They have also been called Neuman bands and Widmanstattian structures. This latter structure undoubtedly does exist in some unannealed welds but is changed on annealing (see Fig. 12).

If carbon in any of its metallographic forms of occurrence were the cause, heat treatment to above the critical range would certainly eliminate them. This is not the case. Heating in a vacuum to 1100 deg. C. for one hour will not entirely eliminate them (Figs. 3 and 4). The same is true of strains or slips. The disappearance of these lines is gradual, however, and is a function of time and temperature. Figs. 7, 8, 9, and 10 show the effect of the surrounding atmosphere upon the structure of the weld. Pure gas-free electrolytic iron electrodes were used in each case. The nitrogen lines appearing in the air and nitrogen welds do not appear in those made in hydrogen or CO_2. The latter gas gave a weld or typical carbon-iron structure, showing quite a lot of oxide spots.

Further evidence that the lines are nitrogen was obtained by heating, side by side, a piece of nitrogen-treated iron with a weld section in vacuum. Samples were run at 100 deg. intervals from 800 deg. C. to 1400 deg. C. for one hour in each case. A marked diminuation in the number of lines appeared at 1000 deg. C. in both the weld and the nitrogenized iron, and at 1200 deg. C. they disappeared entirely. The diffusion of the nitrogen in molten iron appears to be very rapid, as practically all annealed welds show the lines at an appreciable distance back from the line of the weld, in the plate stock (Fig. 15).

An unannealed weld section (Fig. 11) is liable to be most confusing, containing as it does oxides, nitrides, blowholes, and carbon all suddenly cooled. In the clean places, the structure is not unlike coarse martensite (Fig. 12) and is due to the deposition of impurities in geometric lines along the crystallographic planes of the iron. In order to get any clear idea of the constituents of the weld material, it is necessary first to anneal the section.

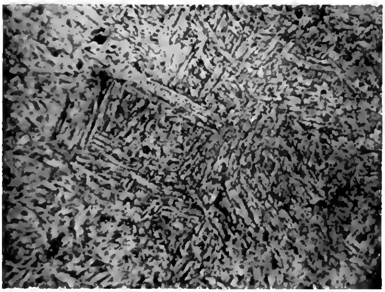


Fig. 12. Unannealed Weld Section. Weld made with standard bare wire electrode

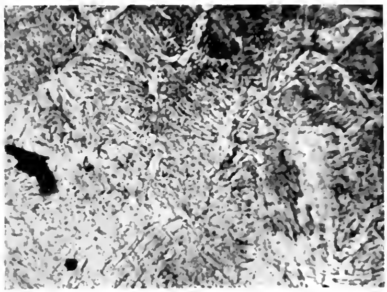


Fig. 13. Edge of Weld Made with Covered Electrode showing Coarsening of Grain in Plate Stock by Overheating (unannealed)

Of the other impurities that may occur in a weld, the sulphur may combine with manganese present and form MnS. It is doubtful if enough sulphur will remain in the weld section to do any great harm. It must be kept at a minimum in both the plate and electrode, as it gives the electrodes very poor working qualities. Phosphorus forms a dangerous phosphide eutectic with iron which tends to form a brittle envelope around the crystals. It should be kept at an absolute minimum both in the plate and the electrode.

Composition

By *composition*, given as the fifth item influencing the quality of a weld, is meant the intentional addition of such elements as nickel, chromium, manganese, silicon, copper, molybdenum, tungsten, or the like. These elements in varying proportions are added to steels to impart specific properties. Sufficient research work has not yet been carried out along this line to warrant any satisfactory conclusions. Chromium or aluminum, it has been found, gives very unsatisfactory results because of the tough oxides which they form. These oxides form a film upon the surface of the metal which effectively resists coalescence with succeeding layers of metal added. Silicon acts much in the same way, but to a lesser degree. The addition of copper has been suggested as a means of minimizing corrosion due to the difference in potential between the weld and the plate. So far, however, corrosion has not proven to be a serious matter.

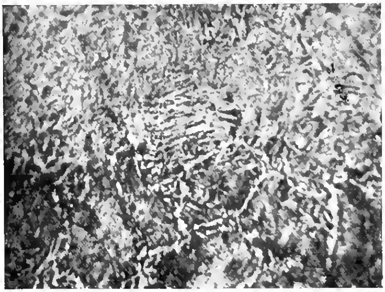


Fig. 14. Section showing Edge of Weld Made with Bare Wire Electrode (unannealed). Shows coarsening of plate by overheating

One other item which must receive consideration is the effect of over-heating the plate during welding. In all welds on fairly heavy sections, this effect is always present and not infrequently so weakens the metal as to cause it to break just outside the weld, giving rise to the mistaken idea that the weld is better than the metal welded. This over-heating causes a coarsening of the grain (Fig. 13) in the metal and a segregation of the pearlite into large masses enclosed in ferrite envelopes. This effect cannot be entirely overcome as the plate must be sufficiently heated to allow of sufficient "burning in."

In general, it must be said that much depends upon the operator, and much difficulty is experienced on this account in comparing data from several sources. For this reason, great difference of opinion still exists on many of these points, but the cooperation of the welding interests in this country and in England through the medium of the Research Sub-committee on welding is making rapid strides toward placing the whole art upon a more scientific basis.

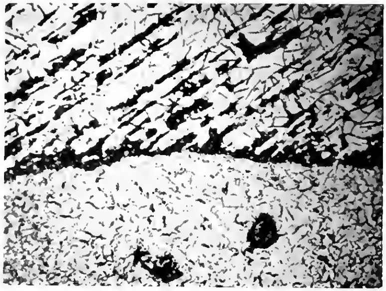


Fig. 15. Section showing Line of Weld after Annealing. Note large number of "lines" appearing in the ferrite of the original plate stock

From the metallurgical point of view as well as the practical, there are yet many problems to be solved, but this does not mean that welding has not yet reached a point of practical application. Its usefulness and economy have been demonstrated in so many industries as to insure its permanency and make its future exceedingly bright.

A Study of the Joining of Metals

By J. A. Capp

Testing Laboratory Schenectady Works, General Electric Company

The purpose of this article, as stated by the author, is to report an investigation made to determine the best practice in making butt welds by the Thomson electric welding machine. Three classes of welds were made, namely: (1), with high current applied for a relatively long period; (2), a smaller current applied for a shorter time; and (3), a current just large enough to produce a welding temperature when applied for the minimum length of time. A microscopic study of these welds shows that the degree of excellence is increasing in the order given; the welds made under conditions (3), after annealing, being hardly distinguishable from the body of the sample bars. The collection of microphotographs clearly shows the character of welds made under each of the three different conditions.—Editor.

The union or consolidation of two pieces of metal is accomplished by processes which are usually described by the terms "welding" or "soldering." When the joining is done by placing the surfaces of the two pieces in close contact and forming the connection directly by pressure, with or without softening by heat, but without fusion of the metals, the process is called "welding."

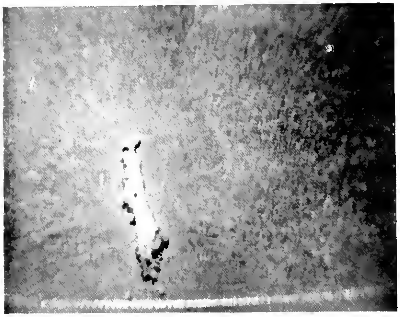
When the joint is made by the use of another or cementing metal which, by fusion, adheres closely to both the surfaces to be joined, the process is called "soldering." Solders are generally alloys, but pure metal, such as tin, is frequently used. Ordinarily the solder is of lower melting temperature than that of the parts to be soldered. Common or soft solders are usually alloys of lead and tin. When hard solders, melting at a red heat, are used, the process of joining is usually called "brazing" and the solders are called "brazing solders," the commonly used materials being spelter (an alloy of copper and zinc), silver solder (composed of silver, copper, and zinc), and gold solder (composed of gold and silver, with or without copper). When the edges or surfaces of the parts to be united are superficially fused into contact and are so consolidated, the process is called "autogenous soldering." The development of means for producing, on a commercial scale, temperatures extremely localized but high enough to melt the more refractory of the metals of commerce has made possible the autogenous soldering even of copper, iron, and steel.

The laxity of common usage has permitted the application of the term "welding," to the oxy-acetylene and the arc welding processes, but strictly speaking these processes should be described as autogenous soldering because the joint is formed by the fusion of cementing material, of approximately similar composition, into consolidation with that of the surfaces to be united.

As used prior to the advent of these processes, the term "weld" conveyed the idea that the surfaces joined were placed in immediate contact and that adhesion was accomplished by the knitting together of the parts directly by pressure, without the use of a foreign cementing material, and without heating to the temperature of fusion but merely to a heat giving great plasticity, i.e., "welding heat." Before the development of the Thomson electric welding process, welding was done only by the smith who brought his work to a welding heat, covered the surfaces with a flux such as borax to dissolve the surface oxide, and then hammered the parts into intimate contact. Why they joined could not satisfactorily be explained until the study of the structure of metals by the aid of the microscope had been developed.

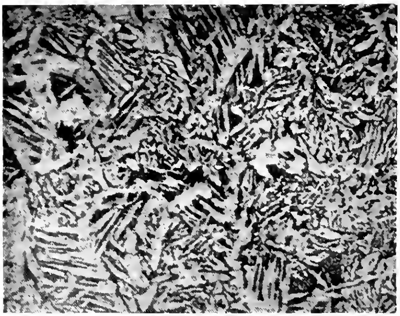
In the Thomson electric welding process the parts to be welded are brought into contact under pressure and then a current of high amperage under low voltage is passed from one part through the joint to the other part. Because of the high resistance at the contact areas, the metal at the joint is quickly brought to a welding heat, when the plasticity of the metal allows the pressure to cause movement of the two parts toward each other. Under the combined temperature and pressure the parts are welded, much as welding was done under the blacksmith's hammer. A flux is seldom required because the parts may be cleaned of oxide before placing in the machine, and the time of heating is too short for serious oxidation to take place during the operation.

The purpose of this article is to report an investigation made to determine the best practice in making butt-welds in the Thomson electric welding machine. The specific problem presented was the development of the technique of welding, whereby it would be possible to join the ends of steel bars in such a manner that the welded bar could be heat-treated, and after such treatment the metal in and about the weld would be as strong and ductile as the metal in the bar away from the weld. Obviously the same practice will apply generally in the making of welds by the

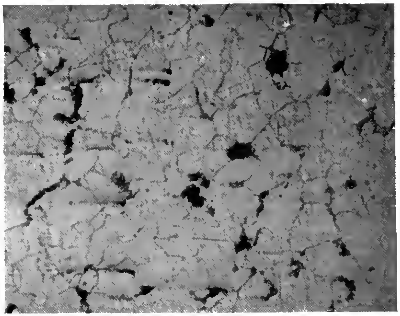


General View of Weld Area. Note large blowhole. 4 diameters.

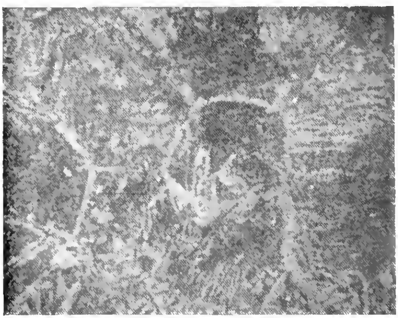
General View of Weld Area. Note blowholes. 4 diameters.



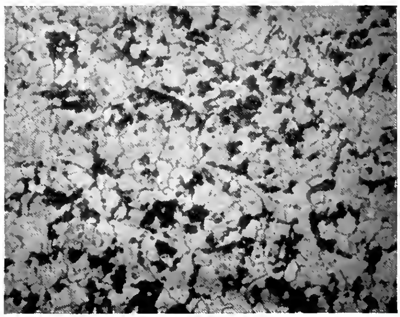
At weld, showing ferrite mass with irregular bands of carbide. Structure in transition stage. 150 diameters.



At weld, showing ferrite grains with a few dots of pearlite. Carbide absent. 150 diameters.



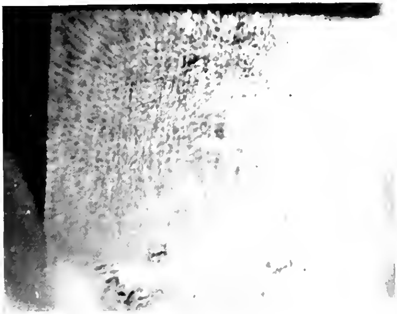
Close to weld, showing large sorbitic grains surrounded with irregular bands of ferrite. 150 diameters.



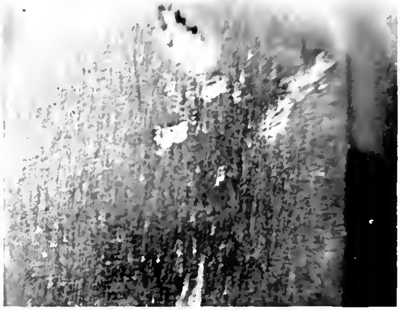
Close to weld, showing ferrite grain studded with pearlite areas. This is the normal structure. 150 diameters.

Photomicrographs of the Longitudinal Section of an Octagonal Steel Sample; No. 6, one inch in diameter between flats, butt welded at 10,000 amp. 6 volts; 3/8-inch movement of clamps; heavy flash produced.

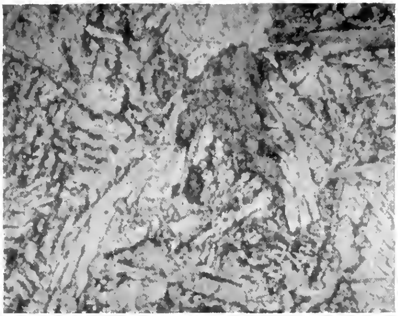
Left-hand column, face of half-sample as welded. Right-hand column, face of the adjacent half-sample after annealing from 875 deg. C. furnace cooled.



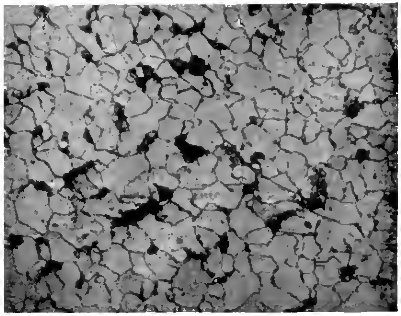
General View of Weld Area. Note large blowholes. 4 diameters.



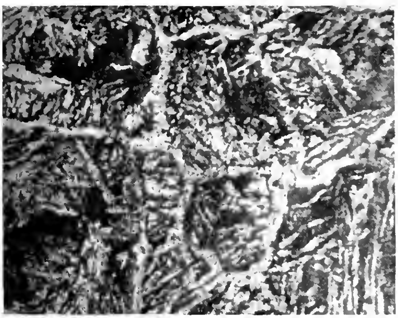
General View of Weld Area. Note large blowholes. 4 diameters.



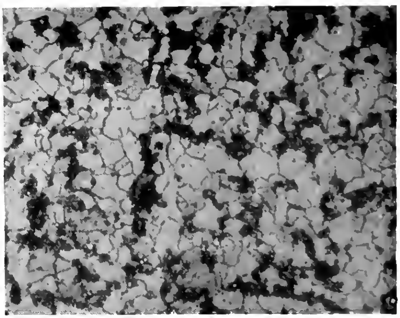
At weld, showing mass of ferrite irregular in shape with a few bands of carbide. 150 diameters.



At weld, showing ferrite grains with a few areas of pearl[illegible]. Carbide absent. 150 diameters.



Close to weld, showing sorbitic grains with ferrite boundaries. 150 diameters.



Close to weld [illegible] areas. This is the normal structure. [illegible]

Photomicrographs of the Longitudinal Section of an Octagonal Steel Sample, No. 16, one inch in diameter between flats, butt welded at 10,000 amp. 6 volts; ½-inch movement of clamps; heavy flash produced

Left-hand column, face of half-sample as welded. Right-hand column, face of the adjacent half sample after annealing from 875 deg C. furnace cooled

Thomson machine, whether the parts are to be used just as welded or whether they are subsequently to be annealed or heat-treated, i.e., quenched and tempered. The essential principles are the same whether the joints are to be made as butt-welds, lap-welds, or spot-welds.

A brief consideration of the physical and structural characteristics of metals in the cast and wrought states will be of assistance in the further development of the problem. Metals are crystalline in structure and the crystals or grains are large or small according to the temperature and the work to which the piece examined has been subjected. When the metal is melted and allowed to cool slowly and undisturbed, there is the greatest freedom of crystal growth. If the cooling is sufficiently hastened, as by pouring the molten metal into a chill mold, the crystals will be markedly smaller than those growing during the slow cooling, and their arrangement, especially at the chilled surfaces, will be different.

Most of the commercially useful metals are malleable either hot or cold; and when wrought by hammering or rolling the coarse casting structure is broken up and a new and firmer order of grain size established. The firmness of this new structure will be determined largely by the amount of work which is done upon the metal and the temperature at which this work is done. Generally speaking, the greater the work and the lower the temperature, the finer will be the grain.

Reheating, to a great extent, will cause a return of crystal size toward that of the cast state; the degree of return is again a function of time and temperature. The reheating of metals to restore grain conditions disturbed by work is called annealing. Generally, the higher the temperature and the longer it is maintained and the slower the cooling during annealing, the coarser the resulting grain. There is usually a minimum temperature below which grain conditions remain practically fixed, but above which grain changes begin to take place and increase in rapidity with rise in temperature above that at which annealing may be said to begin.

These broad generalities apply to practically all metals, including iron and steel. The behavior of these last with respect to heat is, however, much complicated by reason of their passing through allotropic states at certain temperatures and because there is reason to believe that accompanying the allotropic changes there are also changes in the manner in which some of the constituents are chemically combined. Steel is essentially an alloy of iron with other metals or metalloids (such as manganese, silicon, phosphorous, and sulphur) and with compounds of iron with these metals and with carbon.

Without stopping to discuss the several theories which have been offered to account for the changes in steel during heating and cooling, it may be said with sufficient accuracy for our purpose, that steels of the structural variety (that is, having carbon within the range 0.10 to 0.50 per cent) pass through a critical range at a temperature around 750 deg. C. When slowly cooled from above this range, as from 800 or 850 deg. C., they are in their softest or fully annealed state. When the cooling through the critical range is rapid (as by plunging steel at 800 deg. C. in water or oil), there is not time for the changes, usually occurring when slowly passing through the critical range, to take place fully. The quenched steel is somewhat harder and much stronger than the annealed steel; its grain is finer and different in appearance. Such quenched steel, especially if the carbon is over 0.20 or 0.25 per cent, may be somewhat brittle or short, hence it is customary to follow quenching by a partial annealing in which the steel is heated to a temperature below the critical range and allowed to cool slowly. After this drawing, the steel is tough and strong and almost completely relieved of the internal strains induced by the quenching.

The granular structure of slowly cooled cast metal is frequently coarse enough for the crystals to be easily seen without magnification. When grain refinement by working and heat-treatment has taken place, recourse must be had to the microscope if one wishes to study the granular structure. For this purpose, sections are highly polished and then lightly etched with dilute acids or other reagents which attack the material between the grains or at the grain boundaries more rapidly than the material of the grain itself. By this means, the outlines of the grains in the polished plane are brought out in clear definition, and differences in form, color, or appearance of different grains are observable. The structures seen under the miscroscope may be photographed, and a permanent record made of the progress of grain change resulting from the three variables, temperature, time, and pressure.

With any given metal, there may be said to be a grain state and size corresponding to given conditions of work and heat-treatment; and the physical properties of a metal vary with work and heat-treatment. Hence, with known conditions of work and heat-treatment of a given metal, the grain state and size is a reasonable indication of the probable physical properties. It was by means of photomicrography that the proper technique of making electric welds was studied.

The material selected for the experiments was a low-carbon open-hearth steel, obtained under specifications which require the steel to fall within the following specified limits in composition:

Carbon—Not less than 0.13 per cent and not more than 0.25 per cent.
Manganese—Not to exceed 0.30 per cent.
Phosphorus—Not to exceed 0.04 per cent.
Sulphur—Not to exceed 0.05 per cent.

The steel was forged to approximately octagonal form, about one inch diameter between flats. The bars were then fully annealed by heating to 850 deg. C. for four hours, followed by slow cooling. Pieces six inches long were used in the experiments. This length provided five inches for clamping and one inch to project beyond the clamp to meet the bar to which it was to be welded. The clamps of the machine were then set with two inches space between them when the bars to be welded were in contact.

The welding was done in a Thomson electric welder, of 22,000 amperes maximum capacity, in which the clamps were pressed toward each other by a spring.

The experiments were conducted by varying the current used to make the weld and by holding the current for different lengths of time, thereby producing welds with a greater or less amount of movement of the metal in and about the weld. The effects of the various changes in current and time were studied by examination of the accompanying changes in the microstructure of the steel.

The effect of varying the current was to vary the temperature of the metal surfaces in contact and this temperature ranged from about 1200 deg. C., which appeared to be the minimum temperature at which welding took place, up to practically the melting point of the steel. The effect of the varying time of application of the current was to confine the desired temperature close to the surface to be welded, or to permit the high temperature to extend along the projecting ends of the rod from the contact surfaces toward the clamps.

Changes in the condition of actual temperature and extent to which the metal was heated to this temperature permitted a greater or lesser movement of the clamps while the weld was being made, and hence produced a greater or lesser swelling of the metal when welded. If the temperature was low and the heated length of the bars short, there was little or no movement, and hence little, if any, swelling of the diameter at the weld. If the temperature was high and the extent of heating great, not only was the swelling considerable but there was actually a flash thrown out in a ring around the bars where welded. If the temperature was sufficiently high, the throwing out of this flash was accompanied by a shower of sparks of molten metal.

After the welds were made, a one-half inch long section of the welded bars was cut off, the weld being in the center of length of this section. The short section was then cut longitudinally in half.

One of the half-section specimens thus obtained was examined without subsequent treatment; the other specimen was annealed at 875 deg. C. for about one hour, followed by slow cooling. The longitudinal surface taken from the center of the bar in each test specimen was then polished and etched for examination under the microscope.

There were in all about 30 welds made, with varying temperature conditions as produced by variations in current and time. There are presented in this article 36 photomicrographs showing the results on six specimens. Three conditions of welding are illustrated in these six specimens:

(1) The weld made with a high current applied for a relatively long period, which produces a high temperature existing over a considerable length of bar. The result was a weld with a considerable degree of movement of the clamps and an accompanying heavy flash around the bar at the weld.

Photomicrographs of two sample welds, Nos. 6 and 16, which were made under this condition, are shown on pages 948 and 949.

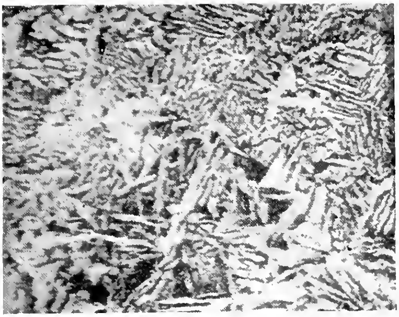
(2) A lower current applied for a shorter time so as to produce a temperature lower than that in the first condition yet of considerable extent. The result of this condition is a weld in which there is a considerable swelling of the metal at the weld and very little flash.

Photomicrographs of two sample welds, Nos. 10 and 3, which were made under this condition, are shown on pages 952 and 953.

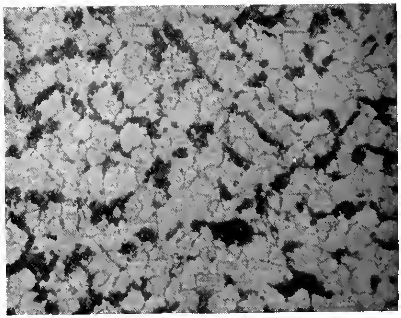
(3) A current just sufficiently high to produce a welding temperature at the sur-

General View of Weld Area. Note large blowholes. 4 diameters.

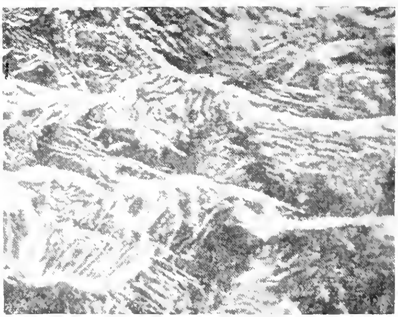
General View of Weld Area. Note small blowholes. 4 diameters.



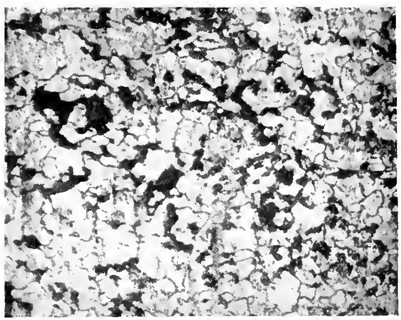
At weld, showing mass of ferrite with numerous plates of carbide. Structure in transition stage 150 diameters.



At weld, showing mass of ferrite grains with nearly normal pearlite areas. 150 diameters.



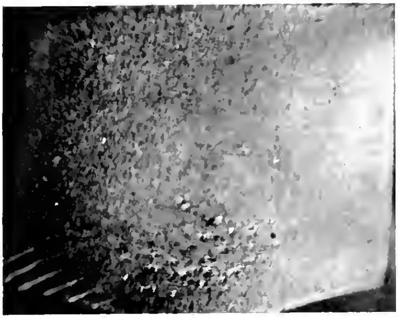
Close to weld, showing sorbitic grains with ferrite bands Note effect of pressure on grains. 150 diameters.



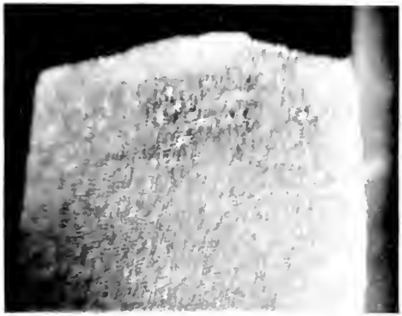
Close to weld, showing ferrite grains with normal pearlite areas. 150 diameters.

Photomicrographs of the Longitudinal Section of a Hexagonal Steel Sample, No. 10, one inch in diameter between flats, butt welded at 10,000 amp., 6 volts, 1/8-inch movement of clamps; light flash produced.

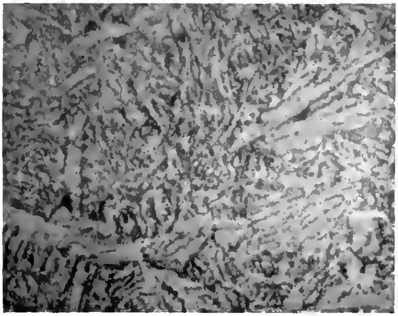
Left-hand column, face of half sample as welded. Right-hand column, face of the adjacent half-sample after annealing from 875 deg C. furnace cooled.



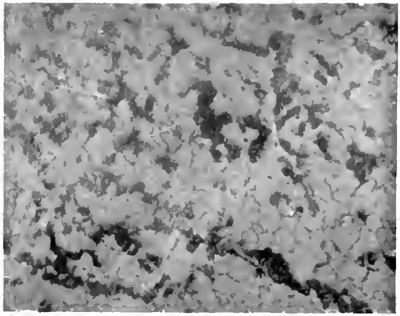
General View of Weld Area. Note group of small blow-holes. 4 diameters.



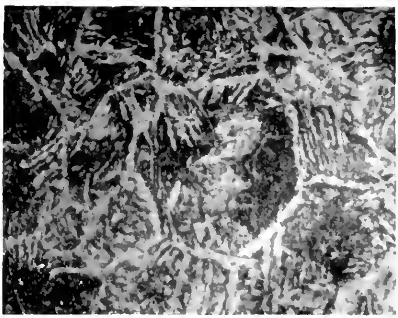
General View of Weld Area. Note [illegible] blow-holes. 4 diameters.



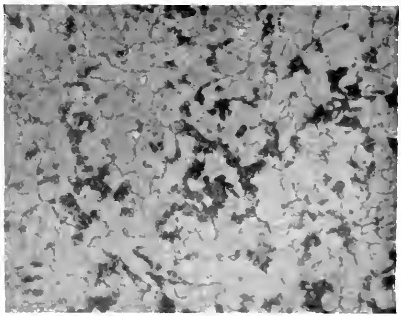
At weld, showing mass of ferrite with numerous plates of carbide. Structure in transition stage. 150 diameters.



At weld, showing ferrite grains with [illegible] areas. 150 diameters.



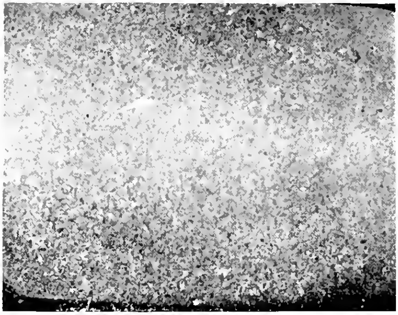
Close to weld, showing sorbitic grains surrounded by irregular bands of ferrite. 150 diameters.



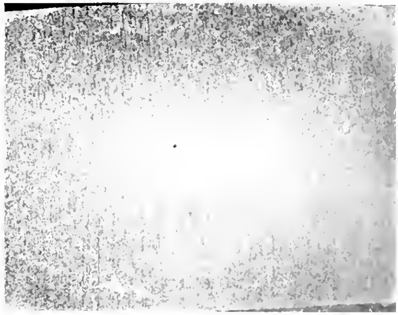
[illegible]

Photomicrographs of the Longitudinal Section of a Hexagonal Steel Sample, No. 3, one inch in diameter between flats, butt welded at 11,000 amp., 6 volts; [illegible] inch movement of clamps, light flash produced.

Left-hand column, face of half-sample as welded. Right hand column, face of the adjacent half sample after annealing from 875 deg. C., furnace cooled.

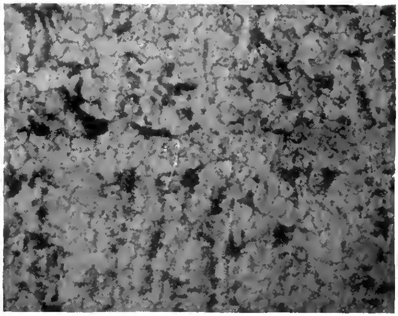


General View of Weld Area. Free from blowholes. 4 diameters.

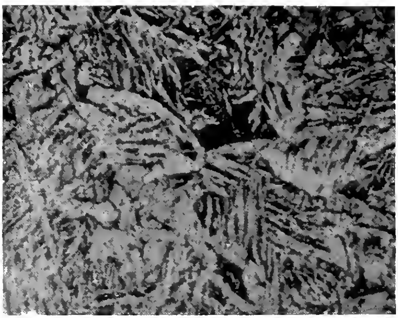


General View of Weld Area. Free from blowholes. 4 diameters.

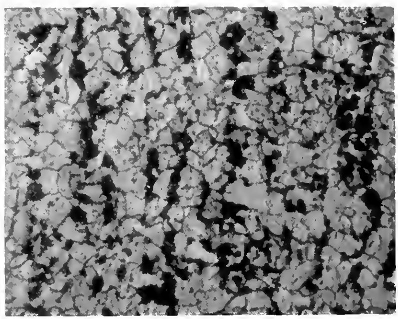
At weld, showing mass of ferrite and carbide in transition stage. 150 diameters.



At weld, showing ferrite streak at junction of specimens. Pressure not sufficient for the low current used. 150 diameters.



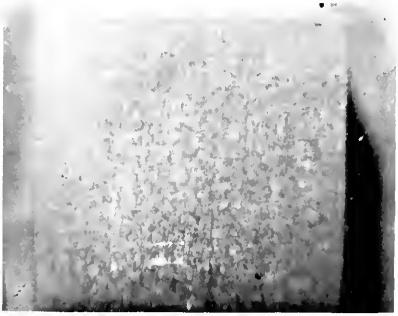
Close to weld, showing structure similar to that in the illustration immediately above. 150 diameters.



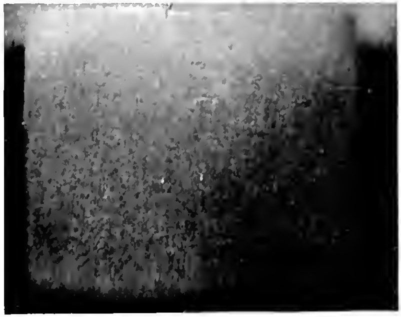
Close to weld, showing ferrite grains with normal pearlite areas. 150 diameters.

Photomicrographs of the Longitudinal Section of a Hexagonal Steel Sample, No. 28, one inch in diameter between flats, butt welded at 7000 amp., 6 volts; no flash produced.

Left hand column, face of half-sample as welded. Right-hand column, face of the adjacent half-sample after annealing from 875 deg. C. furnace cooled

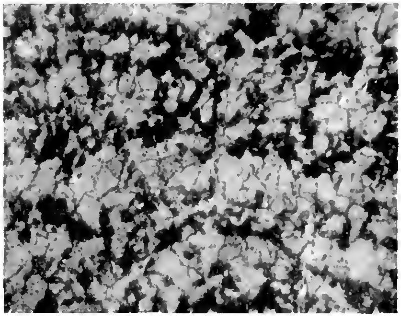


General View of Weld Area. Free from blowholes. 4 diameters.

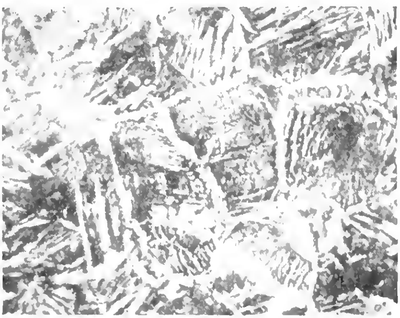


General View of Weld Area. Free from [illegible] 4 diameters.

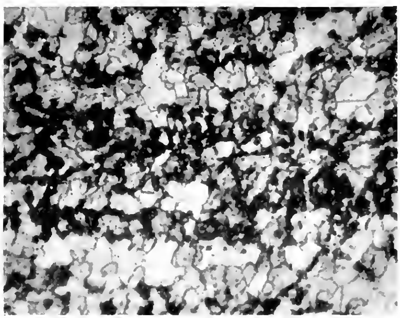
At weld, showing very large sorbitic grains with irregular band of ferrite. 150 diameters.



At weld, showing ferrite grains with [illegible] 150 diameters.



Close to weld, showing sorbitic grains with ferrite bands. 150 diameters.



[illegible]

Photomicrographs of the Longitudinal Section of a Hexagonal Steel Sample, No. 22, one inch in diameter between flats, butt welded at 12,500 amp., 6 volts, no flash produced.

Left hand column, face of half sample as welded. Right hand column, face of the adjacent half sample after annealing from 8[illegible] deg. C. furnace cooled.

faces to be welded and applied for a time only sufficient to bring these surfaces to the desired temperature. The pressure applied then produces a weld with a very slight swell and with no flash.

Photomicrographs of two sample welds, Nos. 28 and 22, which were made under this condition, are shown on pages 954 and 955. The photomicrographs were taken:

(a) At about four diameters to show a transverse section of half the diameter of the bar.

(b) At a point in the heart of the welded area to show the typical structure resulting from welding under the conditions noted. Magnification 150 diameters.

(c) Outside the welded area, but close to the weld, showing the influence of the temperature upon the structure, in the vicinity of the weld. Magnification 150 diameters.

(d) As a longitudinal section through the weld after annealing. Magnification 4 diameters.

(e) Of the structure in the heart of the weld, typical of the welded area after annealing. Magnification 150 diameters.

(f) Of the normal structure of the material away from the weld after annealing. Magnification 150 diameters.

A study of the photomicrographs shows that the welds made under condition (1) result in a considerable decarbonization of the steel in the immediate vicinity of the weld. The structure of the weld itself is irregular and ill-defined. In the immediate vicinity of the weld the steel shows evidence of overheating. Annealing, however, restores the structure close to the weld, but never can restore the normal structure in the weld because of the decarbonization. The weld under such conditions must be weaker than the remainder of the steel.

In welds made under condition (2), the effects of welding are similar to but less pronounced than those observed in welds made under condition 1. There is less decarbonization and less ill-defined grain structure. Annealing brings the welded area nearly back in structure to the normal condition of the steel. Welds made under condition (2), with little or no flash and with a great swell, may be practically perfect but there is liable to be unsoundness due to the fact that there is actual melting of the steel at points where the surfaces are in contact. Such unsoundness is very marked in the case of welds made under condition (1) being found though with less degree in condition (2).

In welds made under condition (3), there is little or no structural disturbance of the steel so far as change of the proportion of structural constituents is concerned. In fact, after annealing it is difficult to say just where the actual weld was made. The photomicrographs taken at low power show no unsoundness because the steel was not melted and gases were not produced. In the experiments made there was evidence shown that the results would have been better had the available spring pressure been higher. It was intended to continue the experiments with increased spring pressure but a necessity for using the machine in production prevented.

The conclusions to be drawn from the work are that welds may be made by the Thomson process so that the metal is structurally the same in the weld as in the areas away from the influence of the weld and that the conditions for such welding are:

That the surfaces in contact and the metal immediately in the vicinity of the weld be heated by the current to a temperature no higher than is customarily used in the smith shop for welding, i.e., 1200 to 1300 deg. C. The temperature must not be applied any longer than is necessary to bring the metal immediately behind the surface to be welded up to the welding heat. The less the length of bar heated for welding the better. The pressure applied during welding must be sufficient to force the metal into actual contact and slightly to deform it.

At the temperature of welding, the metal is plastic and the welding is accomplished by so pressing the plastic surfaces together that the grains of the metal are brought in such intimate contact that grain growth from one piece of metal to the other takes place. Welding made under these conditions is the duplicate of the welding made in the smith-shop. The experiments have shown conclusively that welds made with conditions such that a heavy flash is thrown out about the weld are unreliable and of necessity are weaker than the metal welded because of the structural change resulting from the decarbonization of the steel and because of the blowholes formed when the metal is melted.

HOG ISLAND—ILLUMINATION OF WAYS BY GENERAL ELECTRIC NOVALUX UNIT AND FLOODLIGHTING PROJECTORS

The Butt Welding of Some Non-ferrous Metals

By E. F. Collins and W. Jacob

The process described in this article was the outcome of a search for a satisfactory method of connecting the end rings to the rotor bars of induction motors. One of the first methods employed consisted in bolting the end of the rotor bars to the copper end rings, using lock washers to secure the connection. The high resistance of this joint, which was increased by oxidation as the result of heating, raised the temperature to a point where the temper of the lock washer was destroyed and the connection loosened to a serious degree. The next method was to solder the end rings to the conductors; but poor electrical contact again caused heating and melting of the solder, and the engineers were compelled to look further for a solution of the problem. Electric butt welding gives a perfect electrical joint and admirably fulfills all the requirements; in fact, cases have occurred in practice where the solid copper end ring has melted, leaving the welded joints intact.—Editor.

A fundamental requisite of squirrel-cage induction motor construction is that the rotor bars be fastened to the short-circuiting end rings in such a manner that they will remain permanently in intimate contact. The joints, in addition to being strong mechanically, must possess a low electrical contact resistance. Various methods of fastening were tried in order to meet these conditions.

First, the rings were bolted onto the projecting ends of the rotor bars, with spring lock-washers to secure the connections. Because this type of joint had a comparatively high contact resistance, the heavy short-circuit current in the rotor produced considerable heat which oxidized the two contact surfaces. Obviously, this action further increased the resistance of the connection, and produced still more heat. The temper was thereby drawn out of the lock-washer allowing the connection to loosen mechanically, and the abnormal rise in temperature caused burning of the metal—all tending to cause arcing at the area of contact. Finally, the connection was electrically as well as mechanically severed.

The next proposal was to solder the rings to the bars. The heat due to the contact resistance soon brought the solder to the melting point and centrifugal force threw it from the rotor. Hard solder was then tried, and though it held longer than ordinary solder, the heat, vibration, and centrifugal force tended to break down this connection also.

In every case the difficulty was due to high contact resistance. The union must be of a homogeneous nature since the efficiency of this type of motor depends on the low resistance of the rotor.

A welded connection was next suggested, and as this produces a junction of high electrical conductivity and great mechanical strength, it is used considerably at the present time. The projecting rotor bars surround a toothed end ring, which is of slightly smaller diameter than the rotor. A small block of copper is placed so that it covers the end surfaces of a rotor bar and the corresponding tooth on the end ring, after which it is butt-welded into place.

The operation is carried on in an electric welding machine, as shown in Fig. 1. The projecting rotor bars are shown as *A* in Fig. 2 and the toothed end ring just inside the circle of rotor bars is shown as *B*. A finished weld as at *C* shows block in place. The actual operation is as follows: A rotor bar is tightly clamped to the corresponding tooth of the end ring between the jaws D_1 and D_2. The copper-block end connection is placed so that it covers the combined area of tooth and bar. The movable jaw *E* holds the end connection in place, and heavy pressure is then applied through compression springs. The welding current, furnished by a special transformer having a one-turn secondary, passes from jaw *E* through the surfaces and out through jaw D_2. This heavy current at low voltage causes intense heating due to the comparatively high resistance at the surface junction, and raises the temperature of the copper to welding heat, at which point the metal is plastic.

At this stage, the spring pressure forces the jaw *E* toward the rotor and squeezes out any oxide which may have formed between the welding surfaces. A small stream of water, playing upon the hot area, forms an atmosphere of superheated steam which prevents the formation of oxide and also guards against excessive heating of the copper. No flux is used in the operation as the mechanical squeezing-out of the oxide is sufficient to form a homogeneous connection between the two surfaces.

As the welding jaws approach one another when the metal becomes plastic, an electrical connection is automatically made which operates a solenoid-controlled switch that opens the primary transformer circuit. Thus the current is interrupted as soon as the surfaces have knitted together. The contacts of this automatic switch are placed one on each movable jaw, and are so adjusted that they are separated by the distance necessary for the jaws to approach one

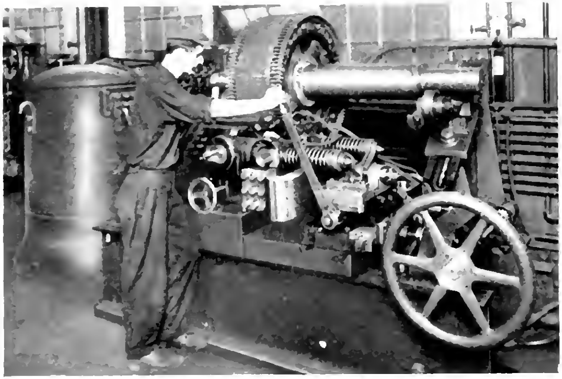


Fig 1 Large Welding Machine for Butt Welding End Rings to Induction Motor Rotor Bars

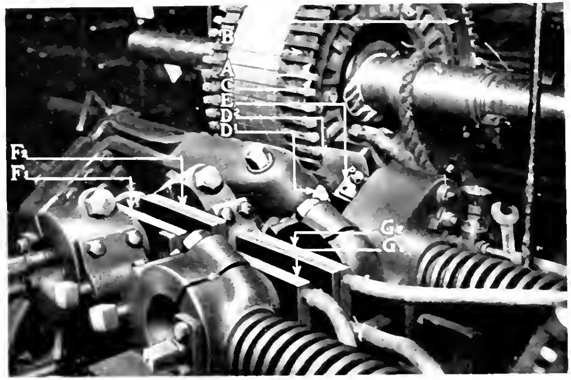


Fig 2. Close up View of Electric Welding Machine shown in Fig 1

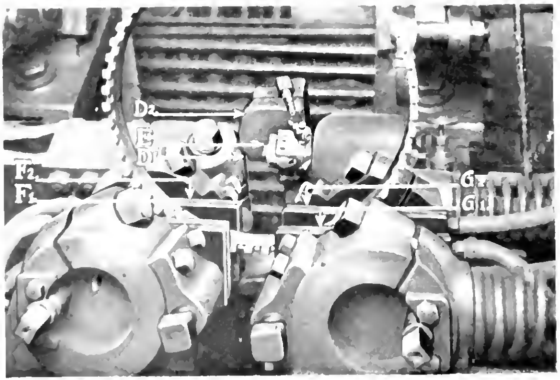


Fig 3 Electric Welding Machine Arranged for Butt Welding Rotor End Ring When arranged in this way, this machine can be used for a great variety of butt welding operations

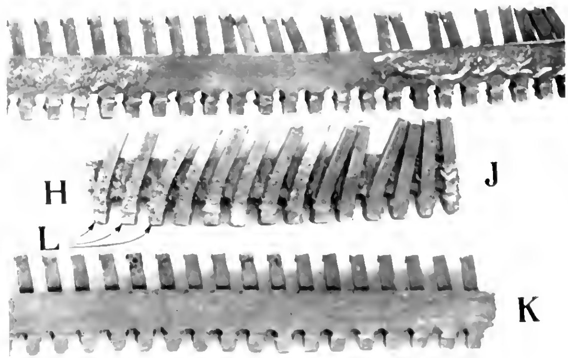


Fig 4 Section of Welded Copper End Ring and Rotor Bars of 150 h.p. Induction Motor Ring melted when motor stalled on line Note that none of the welded joints were affected.

another in forming the weld and in forcing out the oxide. In this way, the end connection is butt-welded to the rotor bar and the end ring, forming a junction of great mechanical strength and low resistance.

Another example of non-ferrous butt welding is the making of seamless end rings, which operation is performed in the same machine using another set of jaws. The operation is shown in detail in Fig. 3 which shows a finished end ring in place. One end of the ring is placed in the vise-jaws F_1 and F_2, and the other is held in the opposite jaws G_1 and G_2. The jaws F_1F_2 approach G_1G_2 and pressure is applied by means of the springs. In all other respects the operation is similar to that of welding the end connections By means of the jaws F_1F_2 and G_1G_2 any two pieces can be welded together, these jaws being adapted to general work while jaws D_1D_2 and E are specially designed for rotor-bar welding.

Rotors up to 14 ft. in diameter are welded n this manner, and Fig. 5 shows an example of the utility of the electric welding machine. The work is done rapidly; for example, end connections with a welding surface of about 0.6 by 0.4 in. are welded at the rate of about 90 an hour.

A unique test of the effectiveness of the welded rotor-bar end connection recently took place. A 150-horse-power, squirrel-cage induction motor with welded end connections was connected to a crusher in a cement mill. During operation an attendant suddenly noticed molten copper dropping from the motor, and then discovered that the motor was stalled. Upon disassembling the motor, it was found that the heat had actually melted the heavy end ring, yet the welded joints were still intact. Fig. 4 shows sections of the end ring hammered flat. Points H, J, and K show where the end ring melted apart. (The bars were sawed off a few inches from the end ring.) The photograph shows plainly the points of excessive heat, and yet it will be seen that each welded joint as at L is still intact.

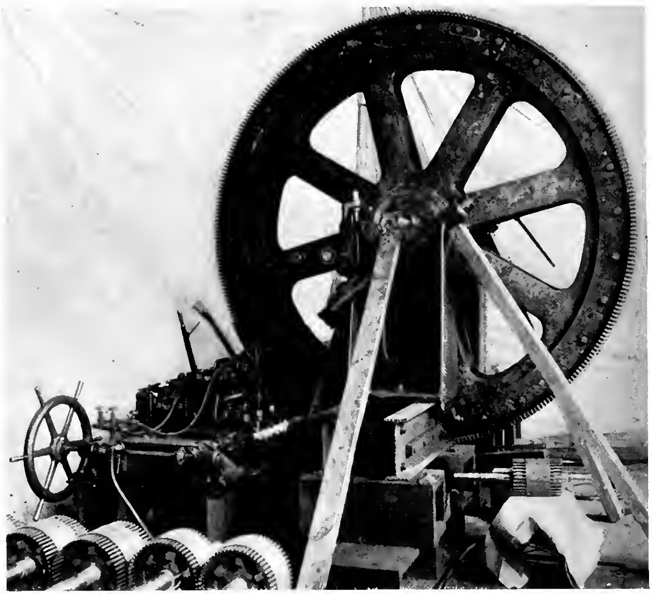


Fig. 5. Showing Latitude in the Size of Work Performed on Electric Welding Machines. The large rotor is for a 1400-h.p. motor and the small rotors are for 5-h.p. machines

Brass rotor bars and end rings are also butt-welded in a similar manner, but the operation is slower. Brass, being an alloy, has a lower melting point than copper, and less pressure is necessary to effect a weld. The pressure is determined by the thickness of the piece to be welded, and should be just enough to form a small "flash" at the point of union. Excessive pressure will cause the molten metal to spurt out from the point of weld. In one fundamental particular the butt-welding of brass differs from that of copper; the pressure on brass must not be released after the stoppage of current until the metal has hardened sufficiently that it will not crack on cooling. This delay retards the rate of welding to the extent that about 60 brass end connections, of the size previously mentioned, require the same time as 90 of copper.

Butt-welding has been the means of producing a rotor having low resistance, high mechanical strength, and ability permanently to withstand vibration and centrifugal force without excessive heating, all of which are essential factors in an efficiently operating squirrel-cage induction motor.

Eye Protection in Iron Welding Operations

By W. S. Andrews

Consulting Engineering Department, General Electric Company

In welding operations three kinds of radiations must be guarded against, one or all of which may be present to an injurious degree. The problem is to provide a perfectly safe filter that will permit of the greatest degree of visibility, and at the same time will exclude the infra-red or heat rays, and the ultra-violet rays. Ordinary glass lenses are usually sufficient protection against the latter radiations; but to shield the operator against the heat rays glasses of special color or combinations of colors are required. The author shows the spectra of a number of commercially available glasses and combinations of these glasses, and a glance at these charts will show what arrangement of filter will provide the best protection against the radiations of the welding arc.—Editor.

Radiation from an intensely heated solid or vapor may be divided under the three headings:

(1) Invisible infra-red rays
(2) Visible light rays
(3) Invisible ultra-violet rays.

There is no clear line of demarcation between these divisions, as they melt gradually one into the other like the colors of the visible spectrum. When the heated matter is solid, such as the filament of an incandescent lamp, the visible spectrum is usually continuous, that is, without lines or bands; but when it is in the form of a gas or vapor, as in the iron arc used for welding operations, the spectrum is divided up into bands or is crossed by lines which are characteristic of the element heated. In Fig. 1, *A* shows the continuous spectrum made by the light of a Mazda lamp operated at normal voltage, and *B* is the line spectrum made by a disruptive arc between iron terminals.

If *A* and *B* (Fig. 1) were colored they would show all the hues of the prismatic spectrum from red at the left to violet at the right, as roughly indicated by the vertical dividing lines. The iron spectrum *B* falls a little short of the continuous spectrum *A* in the red, but it is more intense than *A* in the visible blue and violet, and it also extends further into the ultra-violet. The spectrum *B* contains many lines besides those pertaining to iron, principally those of carbon, nitrogen, and oxygen, these elements being unavoidable components of the electric spark discharge. Inspection of *A* and *B*, however, will serve to indicate the extent and general characteristics of the visible light that is emitted by highly heated iron vapor in the process of arc welding.

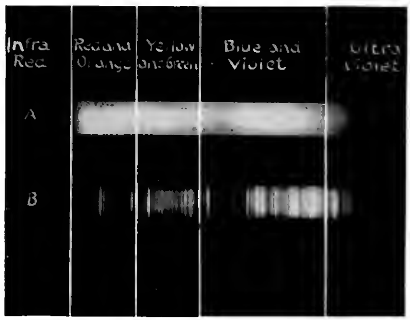


Fig. 1. Spectrum of Mazda Lamp: Spectrum of Iron Arc

The radiations under the foregoing three headings, although of common origin, produce very diverse effects upon our senses. Thus, the infra-red rays produce the sensation of heat when they fall on our unprotected skin.

but they are invisible to our eyes. The visible light rays enable us to see; but we have no sense that perceives the ultra-violet rays, so that we know of them only by their effects.

The intense glare emitted in the process of arc welding consists of a combination of all these rays, and special safety devices are required to protect the operator from their harmful effects.

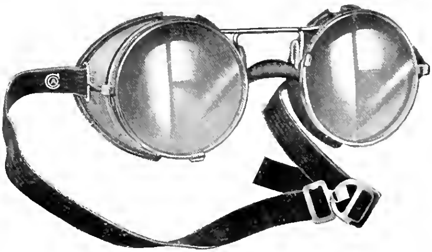


Fig. 2. Goggles

For welding with acetylene and for light electric welding, it may be necessary only to protect the eyes with goggles fitted with suitable colored glasses. Fig. 2 shows a good form of goggles made by the American Optical Co., of Southbridge, Mass., fitted with lenses of Pfund gold glass to which reference will be made later. Fig. 3 illustrates the front and back view of a hand shield which is made of light wood and has a safety colored glass window in the center. This device is used for medium weight electric welding work, which can be done with one hand; and it serves the double purpose of protecting the eyes of the operator and also shielding his face from the heat rays and the ultra-violet radiation, which would otherwise cause a severe sunburn effect.

For heavy electric welding, which requires the use of both hands, it is common practice for the operator to protect his eyes and neck with a helmet fitted with a round or rectangular window of safety glass. These helmets are usually made of some strong light material such as vulcanized fiber and are designed so that they can be slipped on and off easily, the weight resting on the shoulders of the operator. A useful form of helmet with a circular window is shown in Fig. 4. A front and back view of another form of helmet is seen in Fig. 5. It is made of thin sheet aluminum and is supported by a headband.

These safety devices are naturally subject to modifications to meet the requirements of special work, but the illustrations here presented will suffice to give a general idea of such forms as are commonly used.

There are a great many different kinds of special safety glasses on the market, and many combinations of ordinary colored glass are also in common use, so a brief discussion of this very important subject is in order.

It is well known that the normal human eye shows considerable chromatic aberration towards the red and blue-violet ends of the spectrum and that this defect is completely corrected in regard to the middle colors. It, therefore, naturally follows that a much clearer definition of an object is obtained by combinations of yellow-green light than by red alone, or

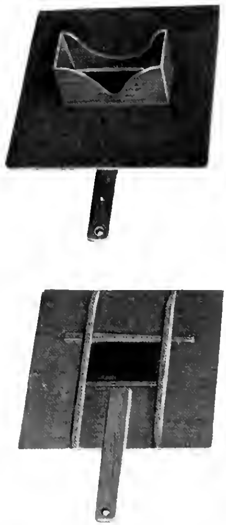


Fig. 3. Front and Back Views of Welder's Hand Shield

especially by blue or violet light alone. The eye is also more sensitive to the yellow and green rays than it is to the red and blue rays; or in other words, yellow-green light has the highest luminous efficiency. This may easily be verified by looking at a sunlit landscape or fleecy clouds in a blue sky through plates of different colored glass. A glass of a light amber color or amber slightly tinted with green will clearly bring out details that are hardly observable without the glass, and which will be obscured entirely by a blue or violet glass. It is therefore obvious that in order to obtain *the clearest definition or visibility with the least amount of glare*, the selection of the *color tint* in safety glasses should properly be decided by an expert; but the *depth of tint* or, in other words, the *amount of obscuration* may be determined best by the operator himself, owing to the individual difference in visual acuity which will permit one man to see clearly through a glass that would be too dark for another man.

A proper selection of color tints can be assisted by spectroscopic examination, and the various spectra shown in the accompanying photographs are presented with this purpose in view.

Fig. 6 shows different spectra made by transmitting the light of a Mazda lamp operated at normal voltage:

C. Through clear colorless glass.
D. Through ruby glass.

Fig. 4. A Popular Form of Helmet with Circular Window

E. Through "Belgian pot-yellow glass."
F. Through emerald-green glass.
G. Through cobalt-blue glass.
H. Through No. 6 "Noviweld" glass.

The screen of clear colorless glass, in *C*, naturally transmits all the colors of the visible spectrum, extending from the extreme red to the extreme violet and penetrating slightly into the ultra-violet because the latter rays, although they are invisible to the eye, are highly actinic and therefore affect the photographic plate. In this case, however, we only see just the beginning of the ultra-violet spectrum, as the glass plate and the

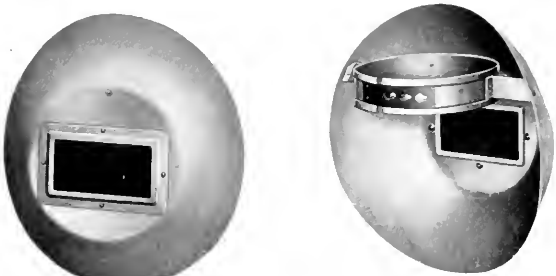


Fig. 5. Front and Back Views of Thin Sheet Aluminum Helmet Supported by a Head Band and Fitted with Rectangular Opening

glass prism of the spectroscope absorb and cut off all but a few of the least refrangible ultra-violet rays.

The ruby glass used as a screen, in *D*, transmits all of the red and orange rays with a trace of the yellow, but it absorbs and cuts out all of the other colors.

The glass used in spectrum *E* is made by the Pittsburgh Glass Co. (Pa.), and is termed "Belgian pot-yellow glass." It cuts off a little of the red, transmits all of the orange and yellow rays and a portion of the green, but cuts out all of the blue and violet.

The emerald-green glass, marked *F*, is seen to transmit all of the yellow and green, with a considerable portion of the red and orange, and also of the blue.

The spectrum made through the cobalt-blue glass, marked *G*, shows the transmission of a band of red and also a band of yellow-green, but it is chiefly marked by its strong transmission of the blue and violet, and especially in its being a little more transparent to the ultra-violet than the clear colorless glass *A*.

These five glasses are samples taken from actual service, but on account of the fact that all colored glasses are subject to considerable variation in tint and depth of color, caused by differences in chemical composition, heat treatment, etc., the spectra shown in Fig. 6

can be considered as only generally representative; samples of blue glass, for example, have been tested, and found to absorb very much more of the red, yellow, and green than the sample shown in *G*.

In *H* is seen a representative spectrum taken through a Noviweld glass (No. 6 grade) made by the Corning Glass Co., Corning, N. Y., which presents an excellent color combination to secure clear definition with the least amount of glare.

It is possible to produce satisfactory color tints for welders' glasses by combining plates of different colored glass. The results of some of these combinations are shown in the spectra of Fig. 7, which were made with the same source of light as Fig. 6. In Fig. 7, *J* shows the full spectrum through clear colorless glass for comparison, the same as *C* in Fig. 6. In *K*, we see the effect of combining yellow and blue glass (*E* and *G* of Fig. 6), which combination makes a fair resemblance to Noviweld, and is giving satisfactory service in certain work where the cost of Noviweld prohibits its use. The tint of this combination is inclined rather too much to the red, and it is somewhat weak in the yellow-green, but these defects could largely be overcome by a careful selection of the plates.

The spectrum *L* in Fig. 7 results from a combination of ruby and emerald-green glass (*D* and *F* in Fig. 6) which has been found satisfactory for certain work and is now used extensively.

The result of combining ruby and blue (*D* and *G* in Fig. 6) is shown by *M* in Fig. 7. It was formerly used to some extent, but is now almost universally superseded by *L*.

The spectrum *N* was taken through a single plate of Noviweld (No. 5 grade) which presents the elements of an ideal color combination, being weak in the red, while transmitting all of the orange, yellow, and green, but totally excluding the blue and violet.

The spectrum *P* was taken through a piece of amber mica having a little darker tint than the No. 5 Noviweld. Its close resemblance to the Noviweld spectrum is remarkable, and if it were possible to procure clear dark amber mica in pieces large enough to be serviceable, this material, when protected from mechanical injury between plates of plain clear glass, would closely rival the Noviweld. Clear dark-amber mica of uniform tint and even cleavage is, however, very difficult to procure, for which reason there is no probability that it will ever supersede glass for protective purposes. In selecting colored glasses, great care should be taken to discard all samples that show streaks or spots, as these defects are liable to produce eyestrain. The glass should be uniform in color and thickness throughout, and the colored plates should be protected from outside injury by a thin piece of clear glass that can easily be renewed.

Having considered briefly the best means for toning down the glaring and flickering visible light produced in the welding process,

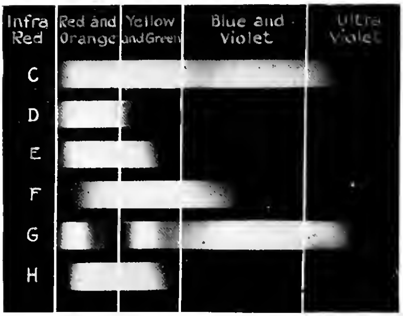


Fig. 6. Sundry Spectra

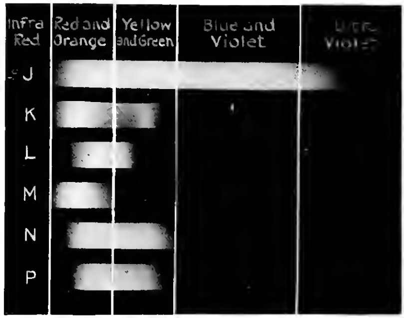


Fig. 7. Sundry Spectra

we may now direct some attention to the infra-red and the ultra-violet rays, which always accompany the visible glare.

When the invisible infra-red rays encounter any material which they cannot penetrate, or which is opaque to them, they are absorbed and are changed into heat. Hence, they are frequently termed heat rays. It is, therefore, very necessary to guard the eyes from these rays; and although they are absorbed to a certain extent by ordinary colored glass, this is not sufficient protection against any intense source. There are, however, several kinds of glass, which, although fairly transparent to visible light, are wonderfully efficient in absorbing heat. Corning glass G-124J is one of these, which, while it transmits 60 to 70 per cent of visible light, cuts off about 90 per cent of the heat rays. The color of this glass is a pale green. The writer has a pair of goggles fitted with plain lenses of this glass and has found them invaluable when operating on high temperature work.

There are also gold-plated glasses, which are superlatively efficient in absorbing and reflecting the infra-red heat rays. A sample of the "Pfund gold glass" previously referred to was found by careful test to transmit only 0.8 per cent of the heat rays generated by a 200-watt, gas-filled tungsten lamp operated at normal voltage, the temperature of the tungsten spirals being estimated at 2400 deg. C. This glass transmits light of a green color and is much darker than the Corning G-124J, so that it probably passes not more than 20 per cent of the visible rays. The Noviweld glasses, especially those of dark tints, are also very efficient shields against the infra-red rays. The effects of even low-power heat rays, when generated in close proximity to the eyes for considerable time, are often serious, as is evidenced by the fact that glass blowers, who use their unprotected eyes near to hot gas flames of weak luminous intensity, are frequently afflicted with cataract which might be positively avoided by wearing spectacles made with plane lenses of the G-124J glass or its equivalent.

Table I indicates roughly the percentage of heat rays transmitted by various colored glasses of given thickness. The source of heat used was a 200-watt, gas-filled Mazda lamp operating at a temperature of about 2400 deg. C. Although the figures are substantially correct for the samples tested, they would necessarily vary somewhat for other samples of different thickness and degrees of coloration, so that they can be taken only as a general guide for comparative purposes.

TABLE I

Kind of Glass	Thickness in Inches	Per Cent Heat Rays Transmitted
Clear white mica	0.004	81
Clear window glass	0.102	74
Flashed ruby	0.097	69
Belgium pot yellow	0.126	50
Cobalt blue	0.063	43
Emerald green	0.100	36
Dark mica	0.007	15
Corning G-124J lt. gr. glass	0.095	10
Dark Noviweld	0.096	4
Pfund gold-plated	0.111	0.8

We now come to the invisible ultra-violet rays, which are principally to be feared not only because they are invisible, but because, as previously stated, we have no organ or sense for detecting them, and we can only trace their existence by their effects. In all cases, however, when we are forewarned of their presence, they are very easily shielded, for there are only a few substances which are transparent both to visible light and to ultra-violet radiation. Foremost among these latter substances, because it is most common, is clear natural quartz or rock crystal, from which the so-called "pebble" spectacle lenses are made. Fluorite and selenite are also transparent to ultra-violet rays, but these crystalline minerals are rare and not in common use. However, a moderate thickness of ordinary clear glass, sheets of clear or amber mica, and of clear or colored celluloid or gelatine are opaque to these dangerous rays. As a case in point, it is well known that the mercury vapor lamp, when made with a quartz tube, is an exceedingly dangerous light to the eye, being a prolific source of ultra-violet radiation, so that when it is used for illumination, it is always carefully enclosed in an outer globe of glass. When the mercury vapor lamp, however, is made with a clear glass tube it is a harmless, if not very agreeable, source of light, because the outer tube of clear glass is opaque to the ultra-violet rays that are generated abundantly within it by the highly luminescent mercury vapor.

When operating with a source of light that is known to be rich in ultra-violet rays, such as the iron arc in welding operations, it is not sufficient to guard the eyes with ordinary spectacles because these invisible rays are capable of reflection, just the same as visible light, and injury may easily ensue from slanting reflections reaching the eyes behind the spectacle lenses. Goggles that fit closely around the eyes are the only sure protection in such cases. Also, when using a hand shield, such as that shown in Fig. 3, the shield should be held close against the face and not several inches away from it.

It may here be mentioned that the invisible ultra-violet rays, when they are not masked or overpowered by intense visible light, produce the curious visible effect termed "fluorescence" in many natural and artificial compounds. That is, these rays cause certain compounds to shine with various bright characteristic colors, when by visible light alone they may appear pure white or of some weak neutral tint. Thus, natural willemite, or zinc silicate, from certain localities (which may also be made artificially) shows a bright green color under the light from a disruptive spark between iron terminals; whereas this compound is white or nearly so by visible light. Also, all compounds of salicylic acid, such as the sodium salicylate tablets which may be bought at any drug store, are pure white when seen by visible light, but show a beautiful blue fluorescence under ultra-violet rays. Many other chemical compounds could be mentioned which possess this curious property, but the above substances will suffice to illustrate the effect of fluorescence produced by ultra-violet rays, and by which these rays may be thereby detected. It must, however, be noted that these substances will only show their fluorescent colors very faintly when viewed by the light of the low-tension iron arc used in welding, because the intense visible light of this arc will overpower the weaker effect of the invisible ultra-violet rays. The true beauty of fluorescent colors can only be seen under a high-tension disruptive discharge between iron terminals, the visible light in this case being weak while the ultra-violet rays are comparatively intense.

Summarizing the effective means for eye protection against the various harmful radiations that are particularly associated with welding operations:

(1) The intense glare and flickering of the visible rays should be softened and toned down by suitably colored glasses, selected by an expert and having a depth of coloration which shows *the clearest definition combined with sufficient obscuration of glare*, which last feature can be best determined by the individual operator.

(2) When infra-red rays are present to a dangerous degree, a tested heat-absorbing or heat-reflecting glass should be employed, either in combination with a suitable dark colored glass, when glaring visible light is present, or by itself in cases where the visible rays are not injuriously intense.

(3) In guarding the eye from the dangerous ultra-violet rays, it must be carefully noted that "pebble" lenses are made from clear quartz or natural rock crystal, and this material being transparent to these rays offers *no protection* against their harmful features. On the other hand, ordinary clear glass is a protection against these rays when they are not very intense, but dark-amber or dark-amber-green glasses are absolutely protective. Glasses showing blue or violet tints should be avoided, excepting in certain combinations wherein they may be used to obscure other colors.

Selecting an Arc Welding Equipment

By J. W. Ham

Power and Mining Engineering Department, General Electric Company

Few things electrical have in so short a period of time created such wide-spread interest as that of arc welding. Engineers having to do with steel products, in whatever form produced or in whatever way employed, have investigated its uses not only as a building agent when applied to new material but as a reclaiming agent for worn or broken parts. In both cases its possibilities as a means of greatly increasing output and in saving otherwise useless parts at a small fraction of their original or replacement value has proved astounding.

Out of these investigations have grown several systems of arc welding that may be designated as,

Constant potential
Constant energy
Alternating current

To exploit these is the duty of the Sales Department and the measure of its success depends upon the quality of service rendered. Service at all times is important and in times such as these it is a positive virtue.

The difficulties of giving service are perhaps not fully appreciated. Where so many systems have been called for and where so many individual ideas have to be met, the problems of the manufacturer become multiplied. It is only necessary to consider the following table to see the amount of material that would have to be carried to insure prompt deliveries.

System	Amp. Capacity	Drive D-c. Volts	Drive A-c.3-phase Volts	Combinations
Constant potential	400	230	All	6
	500	230	All	6
	600	230	All	6
	800	230	All	6
	1000	230	All	6
Constant energy	150	125		1
	(2) 150-2 man	230	220/440	3
	(3) 150-3 man	230	220/440	3
	(4) 150-4 man	230	220/440	3
Alternating current	Various			3
			Total	43

We were asked to conserve food, fuel, and material that the great war might be won. We subscribed to those conditions wholeheartedly, not passively but actively. One form of our effort was to make possible the salvaging of old parts and defective new ones so that they need not be scrapped with consequent waste of material.

The German ships in various United States ports were thought to be beyond repair except by replacing damaged machinery with new. The question of cost was not so vital as that of speed in getting the ships into service. What was actually accomplished by means of the electric arc is a matter of record.

During the period of freight congestion and bad weather last winter, when locomotives were in unprecedented demand, an engine was run into the repair shop with slid flat spots on each of the eight driving wheels, and orders were issued to return it ready for service in record time. In three hours repairs had been completed by means of the electric arc (to have put on new tires would have required three to four days) and the locomotive was out on the road faithfully serving Uncle Sam. Many other achievements as remarkable as these have been obtained.

It would seem that having demonstrated the success of arc welding for a given line of work, others similarly engaged would be keen to take advantage of it; but that is true only in part, possibly because this is a "show me" age Like William Tell, we shoot off the apple, but unlike him, we have to go on shooting off the whole orchard. If a railroad in one locality employs the electric arc to its decided advantage, why should not *every* railroad in the country profit in like manner? If a scheme were devised whereby half the ashes shaken through the furnace grates in our dwelling houses could be reclaimed and turned into fuel "good as new" and at a small percentage of the first cost, would we not embrace the opportunity of conserving fuel and at the same time saving money?

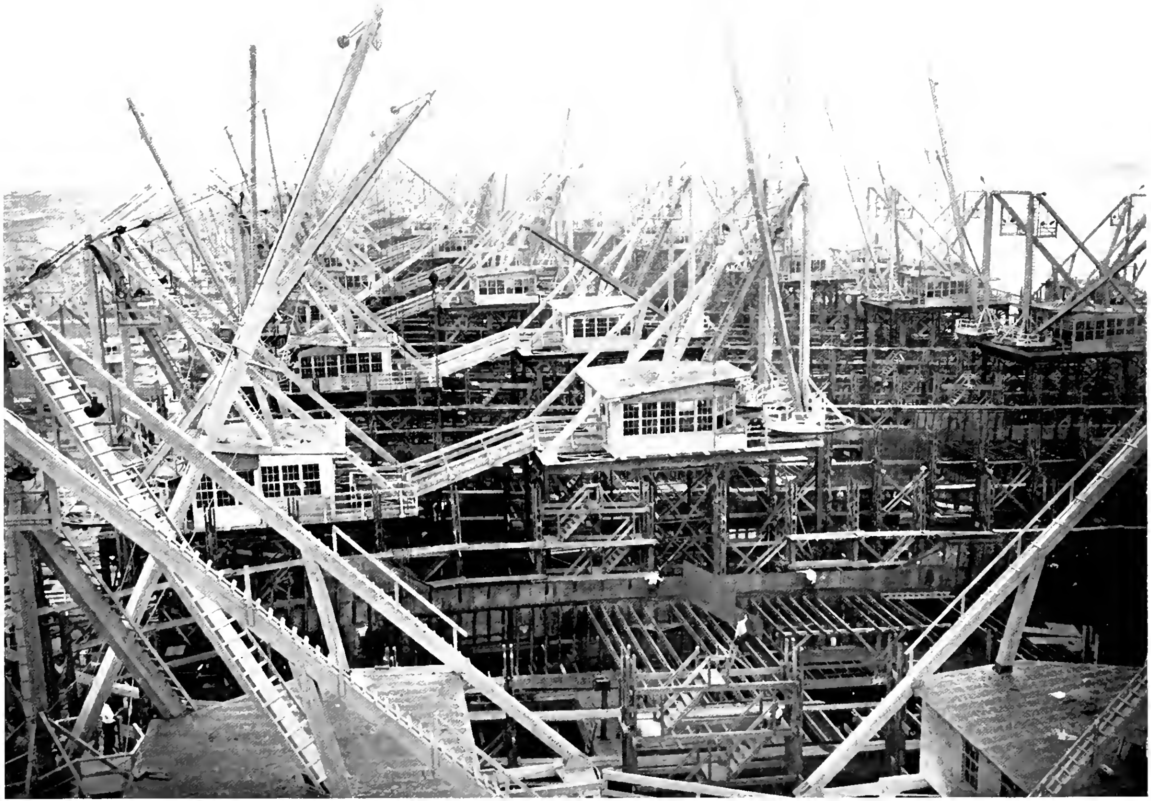
When it becomes apparent to the investigator of arc welding possibilities that the process fulfills his requirements, the question of what system to employ confronts him; salesmen are on the job to tell him about their particular specialties. He is informed that the real secret of welding is having the proper electrode (the salesman's special kind); it must be covered or bare, as the case may be, and contain certain unnamed ingredients. The merits of the direct-current system are extolled. Alternating-current outfits are advocated by others, it being claimed that they bite deeper and weld if the arc is held. The prospective buyer retires with a headache to think it over.

There is no mystery about arc welding. It is being done with all sorts of outfits and many varieties of electrodes. It can even be done from power lines with resistance in series with the arc. But these systems differ widely in essentials, just as in the case of automobiles. We can buy a cheap car or an expensive car, and in either event get about what we pay for; the striking difference, however, being that the low-priced car, in addition to having low initial cost, operates at low maintenance and high mileage per gallon of fuel consumed; while in the lowest first-cost arc-welding system, i.e., one taking power direct from supply line through resistance, the maintenance is small but the results are poor and the cost of operation out of all proportion to the power really required. What is equally important to the purchaser and the power company, is the effect on the power system of unsuitably appointed equipments, such as alternating-current welding outfits of low power factor without condensers.

The arc-welding set must pay its way. It must earn dividends and conserve materials, and when properly selected and applied does both of these things to a degree quite gratifying. To the discriminating purchaser it is not sufficient merely to know that an outfit will make a weld, he wants to know if it is the best weld that can be made, if it can be made in the shortest possible time, and whether the ratio between cost of the entire system to the savings effected is the lowest obtainable. He doubtless will, if the work is of sufficient magnitude to warrant, establish a welding department with a trained arc welding man in charge, and see that this department stands on its own feet. By so doing he places responsibility on a man who knows what to do and how to do it—a friend rather than a foe of the system. He will, other things being anything like equal, respect the opinion of the operator in the selection of the system to be employed, because it is better to provide a man with tools he is familiar with and prefers to use, rather than to force him to use something with which he is unfamiliar or which he regards with disfavor.

Obviously, the purchaser wishes to know that the companies he is dealing with are reliable and responsible, that the experience back of the salesmen is sufficient to warrant faith in his product. It is important to know the amount of power required per operator and whether drawing the needed amount from his own lines or from those of the power company will interfere with the system, and if so to what extent, and what, if any, additional apparatus will be needed to correct the trouble. Having determined these things to his satisfaction, he can install his arc-welding system with a considerable degree of assurance that there will be a decided saving in time, men, and money, and a genuine conservation of materials.

HOG ISLAND—GENERAL RIVER VIEW OF SHIPWAYS NORTHEAST FROM MAIN WHARF



HOG ISLAND—LOOKING EAST FROM WAY No. 1, SHOWING FOREST OF DERRICK MASTS

HOG ISLAND TYPICAL NIGHT LIGHTING OF WAYS

HOG ISLAND—GENERAL VIEW NORTHEAST FROM WAY No. 1

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