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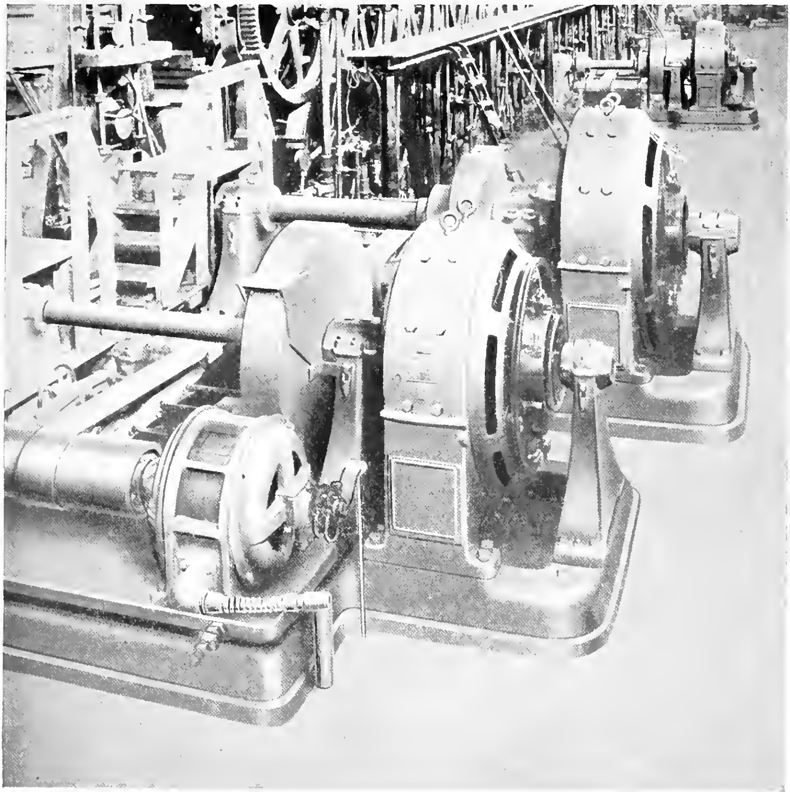
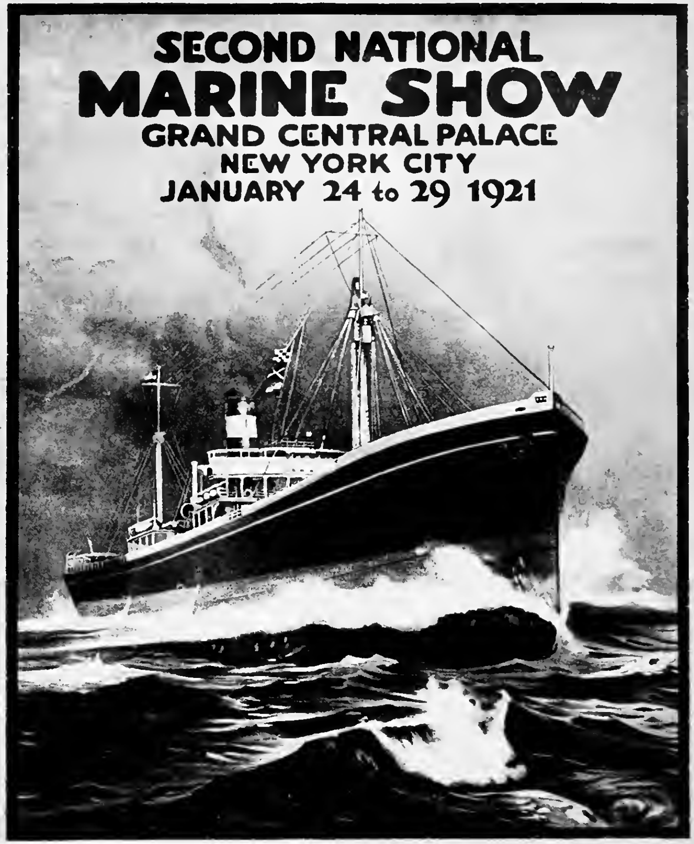


NEW SECTIONALIZED PAPER MACHINE DRIVE IN THE MILLS OF THE CROWN-WILLAMETTE PAPER COMPANY, WEST LINN, OREGON. (See article, page 68)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GENERAL ELECTRIC REVIEW

SECTIONALIZED ELECTRIC DRIVE FOR PAPER MILLS

The electrical equipment commonly employed for driving paper mills comprises a single direct-current motor either belted or direct-connected to the variable speed line shaft. The various sections of the paper machine are connected to this shaft through pairs of cone pulleys to permit of the necessary draw between sections. The motor is supplied with current from a generator of special design driven by either a steam engine or an electric motor, in the latter case the two machines being usually arranged in the form of a motor-generator set. The speed control of the direct-current motor is by the Ward-Leonard principle, which is the most satisfactory method of regulating the speed of direct-current motors where precision is required. This form of paper mill drive is an improvement on steam engine operation as it permits of much wider range of paper speed, with greatly improved regulation, and for the customary speeds at which paper machines are operated it has amply fulfilled the requirements of the trade.

The first consideration in the development of an improved form of electric drive is the elimination of the gear reduction driving each section, with its high maintenance cost and loss of power. Any method other than direct-connected motors is perforce a makeshift and only a half step in the realization of the true segregated drive. Further, the motor equipment must not be complicated, and its method of operation must be such that it meets with the approval of the men operating the machine. Continuity of operation is essential; hence the control must not depend upon contacts, regulators or any other similar devices, for the air in the machine room where these drives are located is often very humid. Since all sections of a paper machine must operate continuously and in unison the failure of one contact-making part to function would cause interruption in production and might even shut down the entire machine.

Until recently there has been no demand for sectionalized drive of the various sections of a paper machine, and electrical manufacturers consequently had not perfected equipment for the purpose, although some ten or twelve years ago a series of experiments were conducted on a form of sectional drive for paper machines which demonstrated its practicability.

The shortage of newsprint during the last four or five years, however, has created an urgent demand for large high speed paper machines; but the application of the old forms of drive at the high speeds required was the principal problem in their realization. Several types of sectionalized electric drive have been offered for the consideration of the paper manufacturer in which some form of special governor is incorporated which cannot act until a change in speed has actually occurred; in other words, an undesirable condition must happen before it can be corrected and there is always a possibility of breaking the sheet before the governor functions. All of these systems leave a great deal to be desired in the way of performance.

As previously mentioned, a group of paper mill specialists connected with the electrical industry had anticipated the present condition in the paper industry, and in their experiments had laid the groundwork for the development of an ideal system of paper machine drive applicable to either high speed or low speed production. This system is entirely different from all other forms of sectionalized drive in that it prevents a change in speed from taking place and consequently does not have to correct it.

The first commercial application of this new form of drive, described elsewhere in this issue, has recently been made to a nine-section high-speed newsprint machine in the mills of the Crown Willamette Paper Company at West Linn, Oregon. The success that has attended its operation ranks it as one of the prominent developments of the past year.

B. M. E.

Some Developments in the Electrical Industry During 1920

By John Liston

Publication Bureau, General Electric Company

About two months ago Mr. Liston told us that his annual story of the year's developments in the electrical industry would be very much shorter than usual owing to the lack of subjects on which to write. However, when he had compiled the material he was greatly surprised at the number and variety of new developments, and the space censor was actually compelled to call a halt. As usual this review is full of interest and faithfully indicates the activities of the industry during the past year.—Editor.

The outstanding feature of the electrical industry throughout a large part of the year was the unprecedented volume of production attained, the impetus of the reawakened demand for electrical apparatus which became intensified in the latter part of 1919 being well maintained through the first nine months of 1920.

Under these conditions development work was confined very largely to detailed improvements in the mechanical and electrical characteristics of standard apparatus and most of the changes effected were along the lines of normal design. There were also a number of new applications and combinations of existing apparatus and some developments which represent a distinct advance over previous practice.

The higher potentials in transformers actually installed and a further advance of this nature undertaken in construction in progress at the close of the year, make possible the commercial use of higher voltage transmission than has heretofore been practicable.

In marine work the use of geared turbine propulsion was extended and electric propulsion was for the first time practically

TABLE I

New York Edison Co., Hell Gate Station	Two 35,000 kw.
Philadelphia Electric, Delaware Station	Two 30,000 kw.
Beech Bottom Power Co., Windsor Station	Two 30,000 kw.
Detroit Edison Co., Marysville Station	Two 30,000 kw
Boston Edison Co., Boston, Mass.	One 30,000 kw
Commonwealth Edison Co., Calumet Station	One 30,000 kw.
Cleveland Electric Illuminating Co	Two 25,000 kw.
Union Gas & Electric Co., West End Station	Two 25,000 kw.
New York Central Railroad, Port Morris Station	One 20,000 kw.

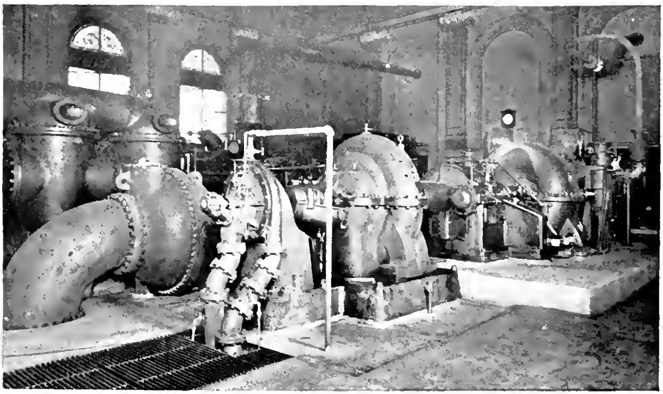


Fig 1. 1275-h.p. Curtis Turbine Direct-connected to Pumps for Municipal Water Supply

applied in a merchant ship and a fishing trawler.

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

similar to those in successful operation in large central stations.

A partial list of the repeat orders received for large machines of this class is given in Table I.

The demand for the intermediate and smaller sizes of turbines was greater than in any previous year.

An interesting example of the application of turbines to mechanical drive has been made for the City of Baltimore. On account of the continuous duty of large municipal pumping sets, economy is of extreme importance and a 1275-h p. turbine (Fig. 1) which was designed for this service has established an unprecedented record for economy and reliability.

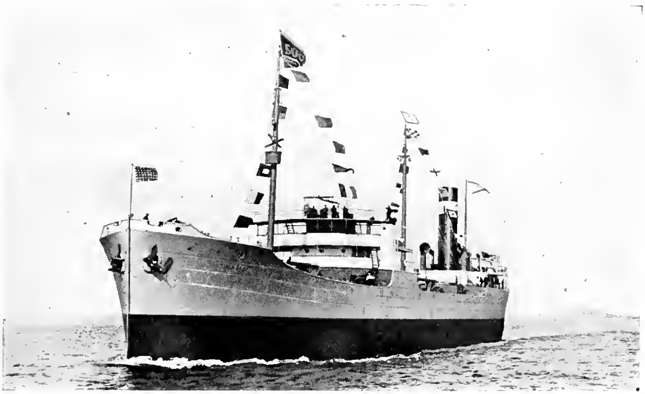


Fig. 2. S. S. *Sucrosa* of the Cuba Distilling Company, 5788 Gross Tons, Equipped with 2400-h.p. Marine Geared Turbine of the Two-plane Type

Turbines

In the central station field developments were largely along the lines of extending or completing existing stations and, in spite of adverse financial conditions, orders were placed for a large number of machines of 20,000 kw., and greater capacity. These machines are of the single cylinder design,

TABLE II

SERVICE RECORD OF ORIGINAL TWO-PLANE TYPE MARINE GEARED TURBINES UP TO OCTOEER 1, 1920

Name of Vessel	Date of Service	Service of Original High-Speed Gears		Service of Original Low-Speed Gears		Total Mileage to October 1, 1920
		Months	Mileage	Months	Mileage	
Pacific	Dec., 1915	27	95,000	59	230,000	230,000
Eurana	Jan., 1916	47	163,000	56	200,000	200,000
Sucrosa	July, 1916	28	120,000	50	200,000	200,000
Niels Nielson	Dec., 1916	46	150,000	46	150,000	150,000
Hanna Nielson	Jan., 1917	45	180,000	45	180,000	180,000
Mielero	Feb., 1917	36	160,000	36	160,000	160,000

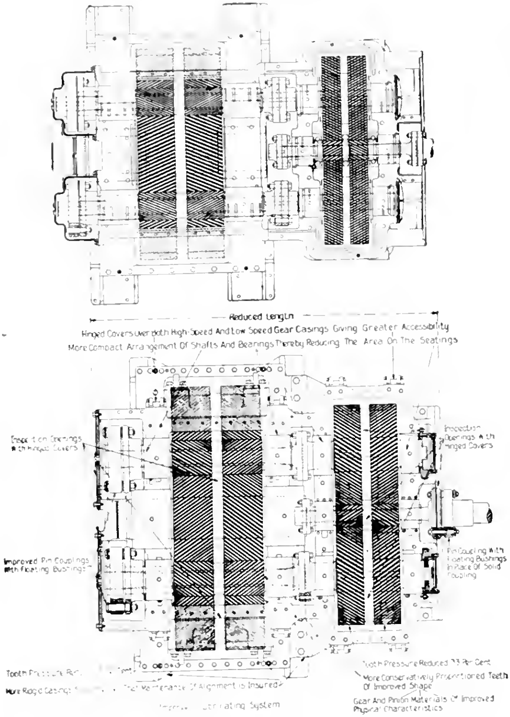


Fig. 3. Comparison of 1914 with 1920 Design of Two-plane Double Reduction Type Marine Gears

Upper Illustration, 1914 Design
Lower Illustration 1920 Design

Marine Geared Turbines

On November 1, 1920, there were 291 cargo ships (Fig. 2) in service which were equipped with G-E marine geared turbines, and during the year the General Electric Company completed the orders which were placed for the emergency war fleet. The last of the geared turbine units were shipped in August and a large part of them have had their trial trips.

The turbine which is now being used for ship propulsion work is practically a duplicate of the unit installed on the S. S. *Pacific* (see Table II), and the gears which are now being manufactured are of the same general design and arrangement as those of the original equipments furnished prior to the war period. Many of the improvements in details which have been worked out due to the large amount of experience gained with marine geared turbines have been incorporated in the 2-plane type gear which is now being manufactured.

The operating record of the original six equipments of this type is given in Table II.

The high-speed gear replacements, where made on the above vessels, have been occasioned by excessive wear on one helix of the high-speed gear caused by the sticking of the low-speed pin coupling. Similar troubles are eliminated in the 1920 2-plane type of gear by employing an improved type of pin coupling with floating bushings for the low-speed pinions, and replacing the solid type of high-speed pinion coupling with a pin

Fig. 4. S. S. *Eclipse*, the First Electrically Propelled Cargo Ship

coupling of a design similar to that for the low-speed pinion.

A comparison of the original 2-plane type gear with that of the 1920 design is shown in Fig. 3. Gears of this type have been installed during the past year in the S.S. *Gray*, *Robin Goodfellow*, *S. M. Spaulding* and *Challenger*.

Electric Ship Propulsion

Assured by the complete success attending electric propulsion as applied to 12 years' continuous operation of the Chicago fire boats, to 8 years' uninterrupted operation of the U.S. Naval Collier *Jupiter* and by the successful two years' operation of the U.S.S. *New Mexico* which wears the efficiency "E" of the Pacific Fleet, we have turned with complete confidence to equipping the merchant marine with electric ship propulsion machinery.

Already merchant ships have been and are being fitted with electric ship propulsion machinery, and the first electrically propelled cargo ship, the S.S. *Eclipse* (Fig. 4) owned by the U.S. Shipping Board and the first American electric passenger and express ship, the S.S. *Cuba* of the Coast Steamship Company, have had very successful official trial trips.

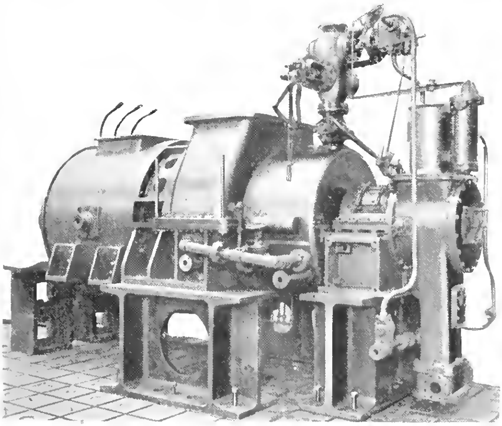


Fig. 5. 3000-h.p., 3000-r.p.m. Marine Turbine Generator Set, Looking Aft

Two types of electric ship propulsion machinery are available, the induction motor and the synchronous motor drive. Eleven more sets for induction motor drive are being built now for the Emergency Fleet Corporation to be installed in cargo ships and four sets for synchronous motor drive are to be installed on the latest U.S. Coast Guard Cutters.

The propulsion equipments for the Emergency Fleet Corporation consist of a marine turbine-generator set (Fig. 5) comprising a

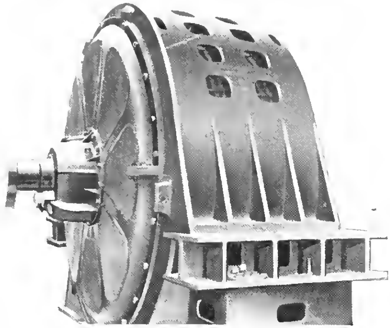


Fig. 6. 3000-h.p., 100-r.p.m., 2300-volt Induction Motor for Propelling Cargo Ship, Showing Coupled End

3000-h.p., 3000-r.p.m. Curtis steam turbine direct connected to a 3-phase alternating-current generator of 2300 volts, supplying power to an induction motor of 100 r.p.m. which is direct connected to the propeller shaft.

Two separate engine-driven generating sets furnish the necessary excitation current for the main generator, one of these being held in reserve as a spare. The one exciter in operation has sufficient capacity in addition to the excitation work required of it to light the ship. For operating the motor in conjunction with the turbine generator a control equipment is installed consisting of a water cooled resistor and a combined control group and control panel.

The motor (Fig. 6) is started, stopped and reversed by means of the high and low voltage contactors of the control group. In starting from rest this water cooled resistor is automatically inserted in the motor rotor circuit. When the motor is nearly up to speed the water cooled resistor is short-circuited by the contactors (Fig. 7) of the control group.

The electric equipments of the U.S. Coast Guard cutters consist of 2600-h.p. turbine generator, a 130-r.p.m., 2300-volt synchronous motor, a control group and panel, and two

75-kw. direct current turbine generator sets for excitation and auxiliary power purposes. The operation of these sets is very similar to that of the induction motor sets as far as switching and necessary operations by the engineer.

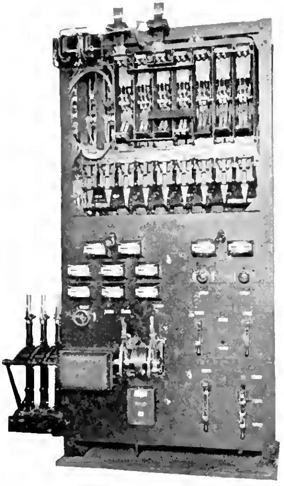


Fig. 7. Contactor Group and Control Panel for Electrically Propelled Cargo Ship

*The first electrically-operated trawler was put in service early in the year and has been in successful operation for ten months. The ship (Fig. 8) is equipped with Diesel engine-electric drive. The control is accomplished from either the engine room or pilot house and the equipment as a whole has proved the reliability and flexibility of this type of propulsion machinery.

U.S. Navy

The decision of the Navy Department to water cool the main propulsion generators and motors for a number of the new capital ships is very important from an engineering standpoint.

The cooler cores will be of the fin and tube type, similar to automobile radiators. Sea water will be circulated through the coolers and the ventilating air from the machines will be driven through the coolers, thus transferring the heat losses to the sea. This is a great improvement over previous practice in which the ventilating air was forced through large ventilators.

The cooler for a given machine is divided into a number of sections so that if a leak should develop in one that section can be readily cut out. Provision is also made to guard against sea water getting into the machines.

The machine losses to be taken care of vary from 600 kw. to 1000 kw., depending upon the capacity of the motor and generator.

The propelling machinery for three battleships and four battle cruisers which is now under construction has a greater aggregate capacity than that of any single group of machines ever produced for this class of work. There are included twenty-two turbine generators ranging in unit capacity from 11,000 kw. to 35,000 kw. with a total capacity of 682,000 kw. and forty-four propelling motors of the form-wound rotor induction type with speeds from 170 r.p.m. to 320 r.p.m. and individual ratings from 7,000 h.p. to 22,500 h.p., the aggregate capacity being 868,000 h.p.

These figures are impressive in that they indicate the extent to which electric propulsion has been adopted for the largest ships of our navy. In fact, this is now the accepted method of propulsion for all capital ships.

Fig. 8. The *Mariner*, the First Electrically Propelled Trawler

* See article in May, 1920, GENERAL ELECTRIC REVIEW

Electric Drive for Auxiliaries Aboard Ships

The investigation to secure the greatest economy in the operation of ships has shown that with steam driven auxiliaries too great a percentage of the total steam has been used by the auxiliary apparatus. To reduce this loss, electrical drive of auxiliaries has been adopted to a greater extent than heretofore.

A large number of generators, motors and control equipment adapted to the special conditions of marine service for winches, capstans, anchor-windlasses, steering-gears, engine-turning equipments, air-compressors, refrigerating apparatus and various pumps have been developed.

Electric Railways

The most notable activities in the electric railway field during the year were in connection with the safety car, automatic substations and steam railroad electrification (Figs. 9 to 16). The safety car has become more nearly a standard design and large numbers are being ordered for congested city service as well as for the lighter and less frequent schedules in the smaller towns.

Additional automatic control equipments for railway substation service, ranging in size up to 1500 kw. (Fig. 11), were ordered by many roads during the year. The 2000-kw. motor-generator set with complete automatic control (Fig. 12) furnished for the Detroit River tunnel electrification has been in successful operation for several months. This is at present the largest automatically operated single unit in railway service.

What is probably the largest single order for automatic substation equipment included eight 1000-kw. control equipments and transformers to be installed in the 1500-volt direct-current substations of the Victorian Railways at Melbourne, Australia.

In New Zealand, a 300-kw. automatic substation equipment which was provided in 1919 for the Christ Church Tramways was put in operation, and its success is indicated by the fact that two additional 300-kw. automatic equipments for the same company are now under construction.

In the United States, work on the electrification of the steam railways was confined to the C., M. & St. Paul Pacific Coast extension, which is now operating entirely with electric locomotives. The five gearless engines which handle the main line passenger trains over this section have operated without interruption since being put in service in the spring of 1920.

The unqualified success of this entire electrification has been testified to by many foreign commissions which visited the road during the year. In almost every case the visitors have carried away the conviction that high voltage direct-current system solves the problem of railway electrification.

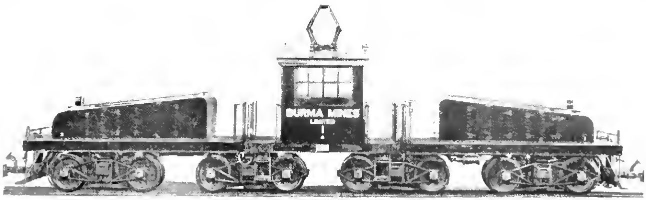


Fig. 9. Electric Locomotive for Narrow Gauge Railway in Burma

The most prominent electrifications which are now actually under way are the Paulista Railway in Brazil (Fig. 13) and the Montreal Harbor Commission at Montreal.

The Paulista Railway equipment includes eight 100-ton freight locomotives (Fig. 14) and four 120-ton passenger locomotives (Fig. 15) designed for operation on a 3000-volt overhead trolley with regenerative braking features for the heavy grade service, complete 3000-volt direct-current substation of 4500 kw. capacity, overhead line material, bonds and transmission line material.

Power will be purchased from the Sao Paulo Light and Power Company at 88,000 volts, 60 cycles, generated principally in water power plants. The initial contract includes 27 miles of double track as the first step in a project covering over 100 miles of road. This road is a trunk line using heavy equipment over a 5 ft. 3 in. gauge.

Fig. 10. Typical Standard Gauge Electric Locomotive Placed in Service in 1920

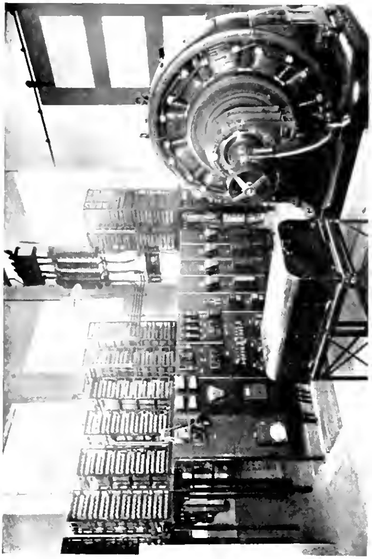


Fig. 11. Automatic Railway Substation of Pacific Electric Railway

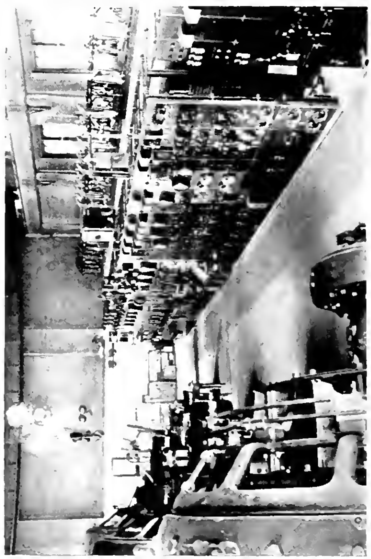


Fig. 12. Substation Serving Detroit River Tunnel Electrification

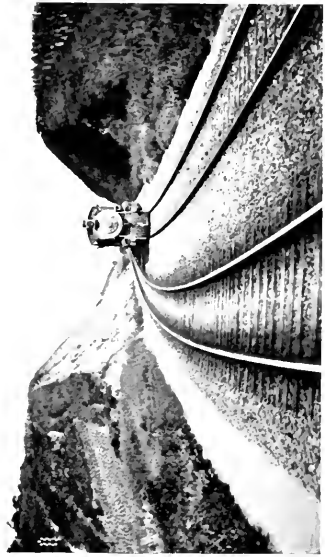


Fig. 13. View on Paulista Railway, Brazil, which is Now Being Electrified

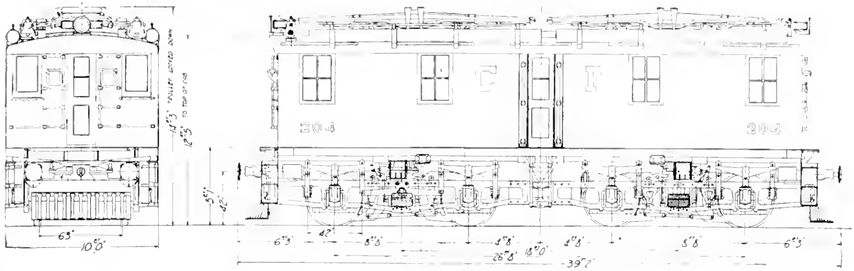


Fig. 14. Outline of "Paulista" Freight Locomotive

The Montreal Harbor Commission during the year made considerable progress in electrifying the terminal trackage around Montreal harbor. These lines extend a distance of about 17 miles on both sides of the St. Lawrence River and are located at the head of ocean navigation, and at the foot of inland navigation through the Great Lakes. There is a total of 58 miles of track extending along the water front and connecting the piers. Connection to the several steam railroads is also included.

The 2400-volt direct-current system was selected for this service after the very successful demonstration of the Canadian Northern Railway lines through the Mount Royal tunnel. The overhead equipment is very similar to that used by the Montreal tunnel, the working conductor being of 4 0 copper wire suspended by loop hangers at the height of 23 feet above the rail. Wooden poles are used from 40 to 65 feet in length, as conditions require.

At present two of the 83-ton, 2400-volt locomotives originally built for the Canadian Northern Railway are being used temporarily for switching service on the finished portion of the line. A 2400-volt direct-current substation is under construction which will contain three 1000-kw. motor-generator sets. These sets are being built by the Canadian General Electric Co. Additional locomotives will be required when electrification is ready for full operation.

Another important project in South America is the Santa Catharina line in Brazil, about 50 miles of which is being equipped for 1500-volt operation with multiple unit cars.

Early in 1921 the Hershey Cuban Railway will start operation over its 75 miles of 1200-volt road. Seven 60-ton locomotives (Fig. 16) are now on the ground for freight work and sixteen motor cars for passenger service. Each of the three substations contains two 500-kw. synchronous converters connected in series for 1200 volts. The control is entirely automatic. A spare 500-kw. converter in each station can be used in place of either the high or low potential machine.

Industrial Haulage Locomotives

Early in the year a new type of gathering locomotive* was produced, which combined

* See article in GENERAL ELECTRIC REVIEW, May, 1920.

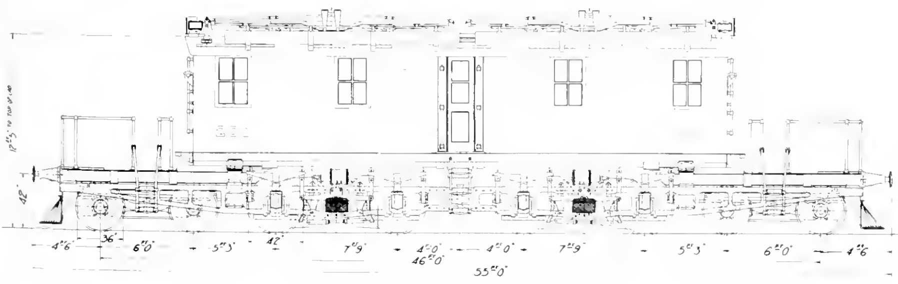


Fig. 15. Outline of "Paulista" Passenger Locomotive

Fig. 16 Hershey Cuban Railway Locomotives Ready for Shipment

in a single two-motor unit, five distinctive features which had successfully withstood a long period of severe operation under varying service conditions.

The important items in the new locomotive (Fig. 17) were a new type of controller by means of which positive and graduated electric braking is secured, the use of outside frame construction, journal leaf springs provided with an equalizer bar, demountable tires for the wheels and an improved cable reel.

The first standard unit of the new line was placed in service in May, 1920, and thereafter the majority of all haulage locomotives produced were built along the same lines in ratings ranging from four to fifteen tons. (Fig. 18)

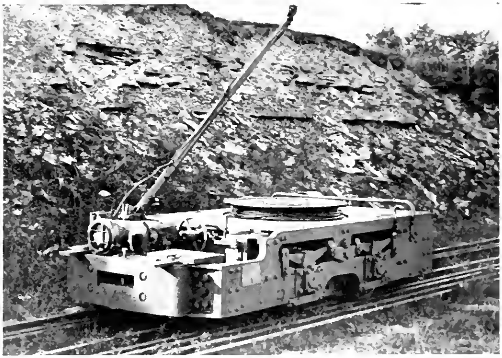


Fig. 17 New Type of Gathering Locomotive Showing Arrangement of Controller and the Use of Journal Leaf Springs

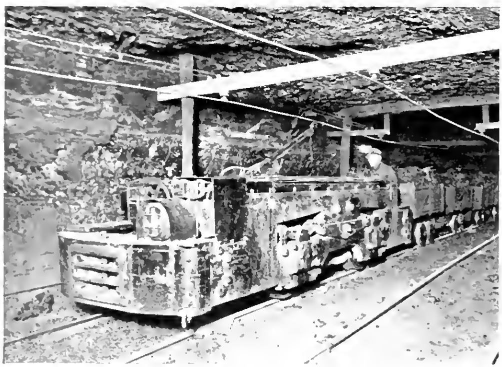


Fig. 18. 13-ton Haulage Locomotive of 1920 Type in Operation in Coal Mine

Perhaps the most important feature of these new locomotives is the electric braking system which is provided on all sizes up to and including eight tons.

The new controller (Figs. 19 and 20) was designed with the view of relieving the motorman of a large part of the labor of braking and operates so that the locomotive is stopped by its own momentum. This is accomplished by providing on the controller reverse cylinder a set of connections that turn the motors into self-excited generators and the energy developed by them is absorbed in the main resistors. The amount of this energy and consequently the degree of braking effort is governed by the main cylinder of the controller. The more resistance cut out of circuit, the more quickly will the stop be made.

The reverse cylinder of the controller is provided with four points (Fig. 21), two for each direction of motion. For the first of these points the motors are connected in the regular motoring position. When it is desired to stop, the main cylinder is thrown off in the usual way, and the reverse cylinder is thrown to the second, or breaking point. The main cylinder is then turned on again and the motors (or generators, as they are now) begin to retard the locomotive.

The degree of braking is under the motorman's control at all times, for if he finds that he is stopping too quickly, he merely has to throw off the main cylinder and permit the locomotive to coast.

In numerous tests it was demonstrated that, with the trolley disconnected, the residual magnetism of the motors, when acting as generators, was sufficient to insure the maximum braking effect with no appreciable difference in the time element involved as compared with the results obtained with the trolley connected. This is an important factor in estimating the all-around serviceability of electric braking for gathering work.

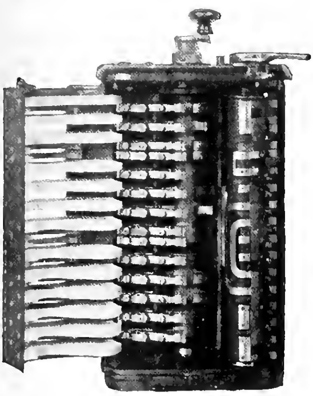


Fig. 19. Electric Braking Controller for Gathering Locomotive

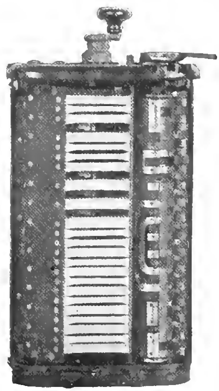


Fig. 20. Arrangement of Restricted Arc-chutes on Electric Braking Controller

On a level track the motorman can bring his train to a dead stop without using the ordinary hand brake at all. He can also bring it to a stop on a grade, but since there is no energy developed when the wheels have stopped turning, the locomotive will start and continue to roll, stop and start again unless the hand brakes are set. A runaway is, however, impossible so long as the train weight and grade are within the braking capacity of the locomotive.

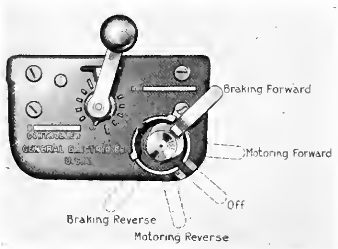


Fig. 21. Top of Electric Braking Controller Showing Control Levers

Two 40-ton storage battery locomotives (Fig. 22) were constructed for general industrial and switching service. They are double truck units each provided with four battery type motors for 200-volt operation by means of 950 ampere hour battery. These locomotives are the largest units of their type so far constructed and are equipped with combined straight and automatic air brake and are arranged for multiple unit control. They have a draw bar pull of 16,000 lb. and, at twenty per cent tractive effort, have a speed of about five miles per hour with a running light speed up to fifteen miles per hour.

These two locomotives can be coupled together (Fig. 23) to form a single 80-ton unit which can be controlled in the same way as either locomotive separately.

Alternating-current Machines

Some of the large units referred to in last year's article as being under construction were completed and installed early in the year. Among these is the 30,000-kv-a., 600-r.p.m., 6600-volt synchronous condenser which is now operating in the Eagle Rock substation of the Southern California system, and which still represents the maximum capacity for machines of this type. The special construction of the rotating element has been fully justified by entirely successful operation for nearly a year. The rotor with a weight of about 170,000 lb. is built up of laminated steel disks instead of the usual cast spider in order to withstand the exceptional stresses imposed by its operation at 600 r.p.m.

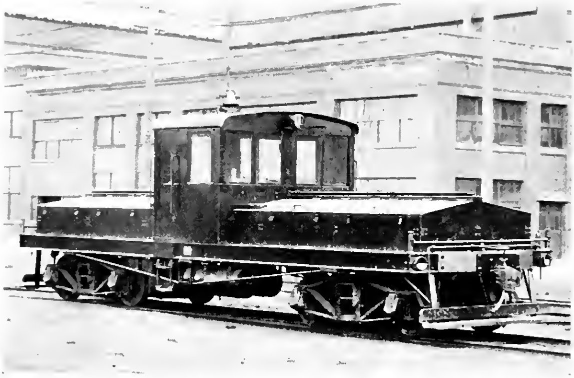


Fig. 22. 40-ton Storage Battery Locomotive

Fig. 23. Two 40-ton Storage Battery Locomotives Operating in Tandem as an 80-ton Unit

The 12,500-kv-a., 22,000-volt synchronous condenser was completed for the Andhra Valley Power Supply Company of Bombay, India. This machine still represents the maximum voltage for synchronous condensers.

The 32,500-kv-a. vertical shaft waterwheel generator at Niagara Falls has been in successful operation for nearly a year. This machine when completed was the largest waterwheel generator ever constructed, but it is interesting to note that there is at present under construction a vertical shaft machine with a rating of 40,000 kv-a., 11,000 volts for operation at a speed of 138½ r.p.m. This will represent the largest rating for vertical shaft waterwheel generators in the United States.

Two horizontal shaft waterwheel generators of greater capacity than any previously constructed were completed during the year for the Great Western Power Company. They are rated at 22,223 kv-a., 11,000 volts, 3 phase, 60 cycle and operate at 171 r.p.m.

Another large horizontal shaft machine for operation at exceptionally high speed was completed and tested. This generator is entirely enclosed, is rated 18,750 kv-a., 6600 volts and will operate at 600 r.p.m.

In vertical shaft waterwheel generators, the capacity on high speed units was carried forward by a 25,000-kv-a., 11,000-volt, 428-r.p.m. unit under construction for the Southern California Edison Company.

Three horizontal shaft waterwheel generators of unusual mechanical design were constructed for operation under conditions where they would be liable to an overspeed of from 80 to 100 per cent in case the electrical load was suddenly removed and the governing mechanism failed to function. These machines are rated at 7,000 kv-a., 14,000 volts and operate at 750 r.p.m., and due to the small diameter of the rotor and the high peripheral speed of the poles, a unique method of pole construction (Fig. 24) was adopted to insure the safety of the machine even under 100 per cent overspeed.

The rotor body and poles consist of a series of steel plates machined to shape; each plate is slotted across the pole face at right angles to the shaft axis to receive the pole tip, which is a separate steel bar machined to the shape of a pole tip as shown at A in Fig. 24. After machining and drilling the individual plates, they were bolted together in two sections and these sections were again bolted together with through-bolts, the whole forming the revolving field without coils. The rotor complete was then shrunk onto the shaft, the shrink fit being required so that there would be a tight fit between rotor and shaft at the runaway speed of the rotor.

Synchronous Motors

A new line of slow speed synchronous motors was developed, primarily for driving air or ammonia compressors. These motors have proved to be both mechanically and electrically superior to any type of motor previously constructed for this service.

Through a simplification of design and a standardization of parts, it is possible to secure with four different frames eighty standard motor ratings and to minimize the quantity and cost of repair parts as well as the cost of production. These motors range from 150 h.p. to 600 h.p. in capacity and operate at speeds of from 150 to 300 r.p.m. An unusual feature of their construction (Fig. 25) is the method of supporting the brush rigging.

In general there was an increasing demand during the year for synchronous motors for various industrial applications such as pumps, ammonia and air compressors, pulp grinders, Jordan engines, cement mills, flour mills and rubber mills.

Weather Proof Dry Dock Motors

Heretofore motors and their control equipment used for dry dock operation have been housed in to protect them from the effects of the variable and severe weather conditions normally encountered in this service.

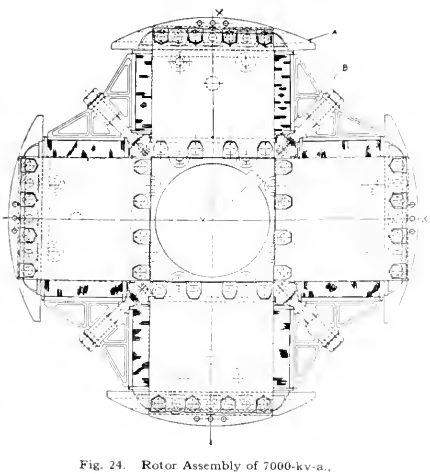


Fig. 24. Rotor Assembly of 7000-kv-a., 750-r.p.m., 14,000-volt Alternator

A weather proof outdoor type of motor was especially designed to meet dry dock requirements and during 1920 seventy units were completed and a considerable number of

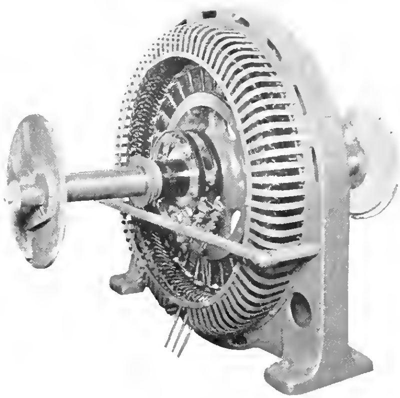


Fig. 25. 170-kv-a., 2300-volt Synchronous Motor, Showing Special Method of Holding Brush Rigging

them were installed on dry docks and operated with entire success without any external protection from the weather.

These motors (Fig. 26) are rated at 75 h.p., 440 volts, 514 r.p.m., 3 phase, 60 cycles and are of the vertical shaft type with the thrust bearing located at the top of the motor frame. They are totally enclosed, self-ventilated and are direct-coupled to centrifugal pumps used for unwatering and sinking the dry docks.

Electrically these units have standard induction motor characteristics but they have special moisture proof insulation and a unique, umbrella-shaped upper bearing housing which insures protection from the elements and at the same time permits of adequate ventilation.

The ventilating fan is located in the lower part of the frame and the air is drawn in under the umbrella-shaped top and expelled through the openings near the base which is bolted to the dry dock deck. The motors can be run at full load for $1\frac{1}{2}$ hours without a distinctive rise in temperature.

Individual automatic control is provided and these equipments are installed in a weather proof steel cabinet located near the motor. These controllers are of the compensator type and give instantaneous phase failure protection, hand-reset, inverse time element overload protection, non-reversing, and provide for remote control from a station located at a distance of not more than 500 ft.

Fig. 26. 75-h.p., 440-volt Vertical Shaft Induction Motor with Umbrella-shaped Bearing Housing for Outdoor Operation on Dry Dock

Direct-current Machines

A complete new line of 4-pole compound-wound, commutating pole, direct-current motors (Fig. 27) were brought out in capacities ranging from 2 to 15 h.p. for operation on 230 and 550-volt circuits.

These motors were designed primarily for the operation of reciprocating mine pumps and, as this service frequently gives very severe operating conditions, the motors are so proportioned as to give an unusual amount of mechanical strength for units of their capacity. The field coils are heavily insulated with tape and varnish and the armature coils are form-wound for maximum resistance to injury from vibration. No fans are provided but the coils are so shaped as to induce ample natural ventilation. Waste-packed bearings are used for both ends of the machine and the general design has been so standardized that only three sizes of bearing linings are required for the seven different frames which give twenty-two motor ratings.

A large number of these motors have been operating mine pumps for nearly a year in locations where they were subjected to moisture, coal dust and acid fumes and have given very satisfactory service.

Oil Wells

The demand for oil well motors continued to increase in both old and new oil fields, but the power companies were unable during most of the year to supply ample power for this purpose.

Electric drilling has been adopted extensively in both Kansas and Southern California. In Los Angeles County, the deepest electrically drilled oil well in the world (Fig. 28) was completed in June at a depth of 4560 feet, this being the "Anita A" well of the Shell Company of California.

The work of drilling this well was handled by a standard 75-h.p. oil well drilling motor equipment (Fig. 29) at an estimated saving of over $14,000 as compared with steam power.

Another development of the year in Southern California oil fields was the application of motor drive to deep drilling by the rotary method. This has progressed to a stage which gives every indication of its complete success.

Fig. 27. 3-h.p., 1250-r.p.m., 550-volt Compound-wound Motor Designed for Mine Pump Operation

Steel Mills

A new high record in the adoption of electric drive of steel mill main rolls was made. Orders covering over 106,000 horsepower (continuous rated) were placed and of this total 29,400 h.p. was made up of adjustable speed alternating-current motors equipped with regulating sets. This increase brings the total of G-E main roll drives to approximately 515,000 h.p. of which 90,000 h.p. are adjustable-speed induction motors with Scherbius control.

The activity in sheet and tin mills was especially noticeable and 19 motors, totalling 22,650 h.p. to drive mills of this type, are now under construction.

Fig. 28. The "Anita A" Well of the Shell Company of California Drilled by Standard 75-h.p. Oil Well Drilling Motor Equipment

The new 14-in. hot strip mill which is being installed by the Trumbull Steel Company, Warren, Ohio, will consist of ten stands, all driven by adjustable-speed direct-current motors, receiving power from two 2200-kw. synchronous motor-generators.

TABLE III

Stand	Horse Power (continuous)	Speed R.P.M.
1, 2, 3, 4	1250	175 to 350
5, 6	1250	175 to 350
7	800	200 to 400
8	800	231 to 462
9	800	256 to 512
10	800	275 to 550

The arrangement of the mill with respect to the drives is shown in Table III.

The control requirements for this mill are most exacting. The several stands of the mill are located close together and the steel is rolled at an unusually high speed, making it necessary to provide for very close adjustment of the speeds and for maintaining these speeds with wide fluctuations in load to prevent the development of loops or stretching of the steel between the stands.

The Illinois Steel Company is also installing two hot strip mills which will be driven entirely by alternating-current adjustable speed motors with Scherbius speed control. Each mill will be made up of two high stands, the 20-in. mill comprising 10 stands and the 12-in. mill 12 stands. The equipment driving these mills is listed in Table IV.

The equipments for three reversing mills for rolling copper are being built for the American Brass Company. Each mill is driven by a 350-h.p., 275/470-r.p.m. reversing type direct-current motor, the power for which is supplied from 300-kw. synchronous motor-generators.

Among the large equipments purchased for foreign shipment, that for the United Steel Company, Sheffield, England, is especially worthy of mention. This equipment includes three adjustable-speed induction motors with Scherbius speed control:

Mill	H.P. (continuous)	Speed R.P.M.
12-in. Merchant	3000	470/280
12-in. Merchant	2500/1670	240/150
12-in. Hoop	1500/805	325/175

For the Tin Plate Company of India, three 1000-h.p., 300-r.p.m. induction motors for driving tin mills and one 750-h.p., 500-r.p.m. motor for driving cold mills.

For the Tata Iron & Steel Company, Sakchi, India, a d-c. reversing type motor for driving a combination rail and structural

TABLE IV

Mill	Stands	Horse Power (continuous)	Speed R.P.M.
20 in.	1 to 9 inclusive	5500/3400	170/105
20 in.	10	2070/1205	235/137
12 in.	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	2750/1750	262/167
12 in	5	300/165	333/187
12 in.	11	750/460	360/220
12 in.	12	750/440	473/278

mill. The equipment consists of a double unit motor (Fig. 30) rated 6300 h.p. at 80 r.p.m., with control from 60 to 120 r.p.m. Speed control from 60 to 80 r.p.m. is effected by control of the generator fields and control from 80 to 120 r.p.m. by control of the motor fields.

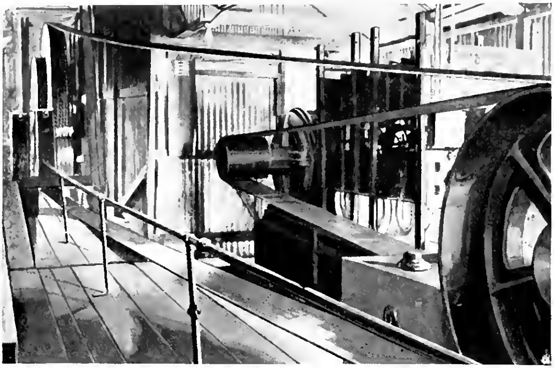


Fig. 29. 75-h.p., 720-r.p.m., 440-volt Induction Motor Operating Oil Well Drilling Equipment

Power for this reversing motor unit is supplied from a flywheel motor-generator set consisting of a 6500-h.p., 375-r.p.m. induction motor, two 2500-kw., 375-r.p.m. generators and one 50-ton flywheel. This equipment is normally operated non-reversing, but the motor may be quickly stopped or reversed if necessary.

Mining

The activity in mining was not quite up to that of some former years, but a number of interesting large equipments and an unusually large number of small hoist motors from 100 to 250 horse power were installed or under construction at the close of the year. Among these were 97 units, totalling 27,150 h.p., of which 59 units totalling 8900 h.p. were in the smaller capacities.

The McKinney Steel Company's hoist at Bessemer, Mich. (Fig. 31), was put into commission and has given a good account of itself. This is the largest direct-current iron ore hoist in the United States. The drums are cylindrical and are driven by a 1650-h.p., 80-r.p.m direct-connected motor. In addition to the main hoist there is a man and material hoist driven by 400-h.p. induction motor. In order to reduce the combined hoist peak loads the current for the man and material hoist motor is taken through the slip regulator motor, thus taking advantage of the flywheel of the motor-generator (Fig. 32) supplying the main hoist motor to smooth out the peaks of the small hoist.

An 1800-h.p., 360-r.p.m. induction hoist motor for No. 6 Muscoda slope for the Tennessee Coal, Iron & Railroad Company is being built. This motor will be a duplicate of the one now in operation at the No. 4 Muscoda slope and will hoist 26,880 lb. of ore per trip from a maximum distance of 6000 ft. along the slope at an average inclination of 21 degrees from the horizontal, which corresponds to approximately 290 short tons per hour. The hoist differs from the one at No. 4 slope in that it has a double drum, hoisting being done in balance, while at the No. 4 slope hoisting is done out of balance.

The Miami Copper Company will install a 1400-h.p., 325-r.p.m. Ilgner Ward Leonard hoist equipment to drive a double cylindrical drum having a capacity of 20,000 lb. of ore per trip, hoisting in balance, from a maximum vertical depth of 1065 ft. This corresponds to approximately 530 tons of ore per hour.

Two large hoists are under construction for foreign shipment, both of which are of the Ilgner Ward Leonard type. One of these equipments will be installed at a Belgian mine and the other in the Orient. The Belgian hoist is of the Koep pulley type, approximately 20 ft. in diameter and will be driven by a 1150 h.p. direct-connected motor running at approximately 32 r.p.m. 13,200 lb. of ore will be hoisted per trip from a maximum vertical depth of 2950 ft., which corresponds to 200 short tons per hour.

The Furukawa equipment is a double conical-drum second motion hoist, driven by a 1150 h.p., 350-r.p.m. direct-current motor. This equipment operates in balance and is capable of hoisting 13,440 lb. per trip from a maximum vertical depth of 1300 ft., which corresponds to approximately 450 short tons per hour.

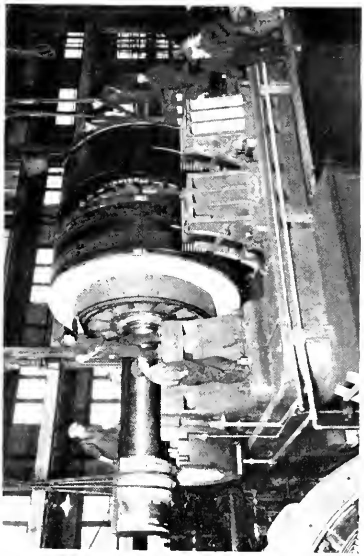


Fig. 30. 6300-h p. Steel Mill Motor in Process of Assembly in Factory

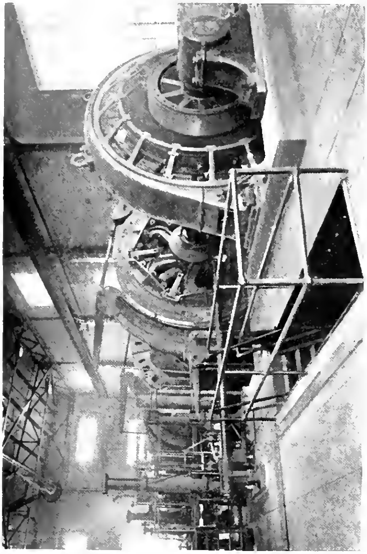


Fig 31. 1650-h p., 80-r p m., 525-volt Direct-current Motor, Direct-connected to Double Drum Mine Hoist of McKinney Steel Company at Bessemer, Mich

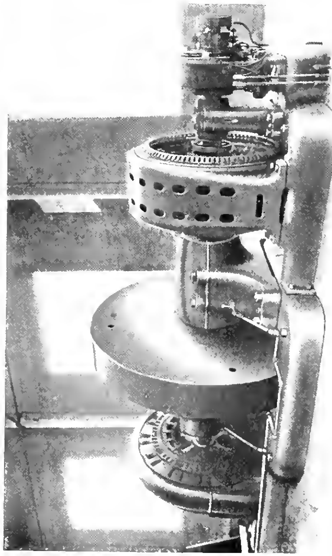


Fig. 32. Flywheel Motor generator Set Supplying Current to Mine Hoist Shown in Fig. 31

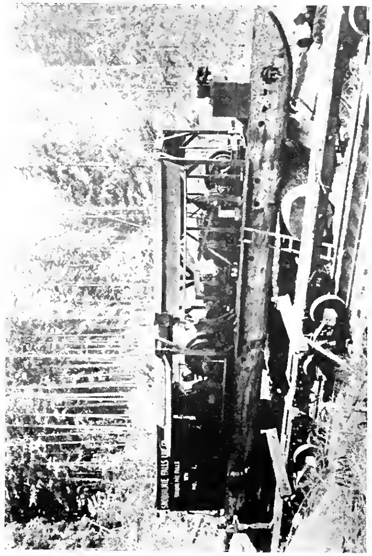


Fig. 33. Combined Yarder and Loader Hoists Used in Lumbering Operation of Snoqualmie Falls Lumber Company

Electric Logging

A unique installation which will undoubtedly have a considerable influence on the future of the lumbering industry consists of a combined outfit of electrically-operated yarder and loader hoists (Fig. 33) which was placed in service in August, 1920, by the Snoqualmie Falls Lumber Company of Snoqualmie, Wash. This outfit has been in successful operation from the time it was installed and electrical apparatus for a number of similar equipments is now under construction.

The yarder is operated by a 200-h.p., 600-r.p.m., 3-phase, 60-cycle, 550-volt motor of special construction designed particularly for the very high torque which is essential in yarder service, this particular unit being warranted to give 400 per cent of normal operating torque momentarily.

The motor, which has a greater capacity than any machine used previously for this service, is of the slip ring, form-wound induction type provided with weather-proof coils and is self-ventilated by means of a fan located on the rotor. Permanent resistance is mounted in the secondary circuit of the motor to give smooth acceleration and maximum starting torque, regardless of how rapidly the operator throws the controller to full running position.

Fig. 34. Use of Tree Trunk for Handling the Yarder and Hoisting Cables for Hauling in Logs and Loading Them on Railroad Cars

Fig. 35. Arrangement of Outdoor Transformer Equipment, Showing Method of Mounting on Sled and Location Near Railroad Track

Control of the primary circuit is effected by means of contactors, with a drum controller connected in the secondary circuit, and the electrical equipment includes a solenoid brake and overload relay.

The motor is gear-connected to the hoist which serves an area within a radius of from 600 to 800 ft. The main haulage cable is 1200 ft. in length and the average rope speed is about 400 ft. per minute with a maximum pull of about 72,000 lb.

The loader, which lifts the logs brought in by the yarder and deposits them on the railway cars, is a duplex outfit with two hoists each gear-driven by a 75-h.p. slip ring motor with drum control through contactors and an overload relay. These hoists are not provided with mechanical brakes but each has two electrical brakes, one being the standard solenoid type, and the other a solenoid load brake which has inherent graduated braking characteristics. The reason for this double brake equipment is to secure low and fully controlled lowering speeds when placing the heavy logs on the cars. Both the yarder and loader cables are run through sheaves which are installed on a heavy spar tree (Fig. 34) located near the railroad track.

Current is supplied to the motors from a steam turbine generating station, located at a sawmill about five miles from the present operating area, over a 13,200-volt transmission line to step-down transformers which transmit current directly to the motors at 600 volts through a flexible three-conductor cable. The yarder and loader outfit and the transformers are mounted on gigantic timber sleds (Figs. 33 and 35) which can be slid onto railroad cars for transportation.

At present there are under construction seven 300-h.p. motors with magnetic control for yarders and ten 75-h.p. motors for loaders, which indicates that the initial installation during its six months' operation has successfully met the requirements of the special service for which it was designed.

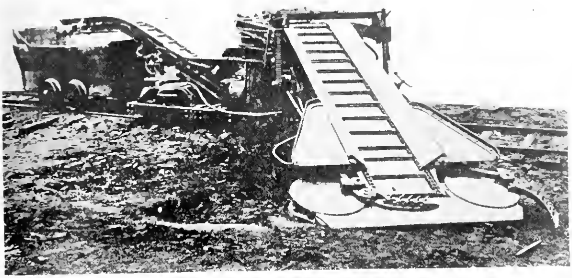


Fig. 36. Coal Loading Machine Showing Arrangement of Gathering Arms at the Foot o the Gathering Conveyor Belt

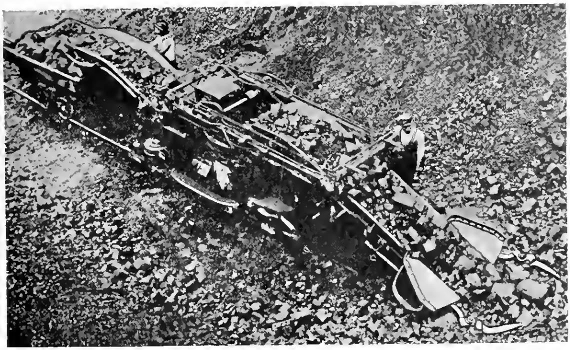


Fig. 37. Coal Loading Machine Showing Installation of Motor in Center and Complete Travel of Coal from Face to Mine Car

Coal Loaders

In view of the high cost of labor in coal mines, an unusual amount of attention has been given to the development of coal loading machines and some very efficient types have been produced which can propel themselves to various locations in the mines or on the surface to meet changing demands for their service. These are of two general types, one of which requires rails for its transit, the other being equipped with caterpillar tread.

Ten coal loaders of the type shown in Figs. 36 and 37 are equipped with five motors each. These loaders were constructed by the Joy Machinery Company for the Pittsburgh Coal Company and their operation is briefly as follows:

The intake portion of the machine is brought close to the face of the coal seam and, as the coal is shot down, it falls on to the first conveying belt. It is assisted in reaching the belt by mechanical arms or hands (Fig. 36) which are located on rotating disks on either side of the foot of the conveyor. The conveyor deposits the coal into a hopper through which it passes to a second conveyor belt which carries it to the mine car (Fig. 37). During the interval between removing loaded cars and bringing up empty ones, the delivery conveyor belt is stopped and the coal from the first conveyor accumulates in the hopper. The motors on the truck of the machine are used for propelling the entire machine by means of traction wheels running on the mine tracks; two 5-h.p., 800-r.p.m. motors series wound for parallel operation being used. The service required of these motors also involves holding the machine against the working face which necessitates a certain amount of jogging and plugging.

Fig. 38. Coal Trimmer at Bottom of Telescopic Chute, Showing Location of Operator's Cage

The motors which serve the hopper drive the conveyor which delivers the coal to the mine cars; two 5-h.p., 800-r.p.m. compound wound motors being used for non-reversing service with occasional start and stop.

A motor is also located at the top of the machine and actuates the swing motion of the gathering conveyor or swing motion of the hopper by means of a clutch. Both swings are not operated simultaneously and neither is operated while gathering. The principal duty is to gather and convey the coal to the hopper.

The conveyor belt and gathering arms constitute a single motor drive, utilizing one 12 h.p., compound wound, special motor, 700/900 r.p.m.

In designing these motors it was necessary to keep in mind the space limitations which are of necessity involved in the construction of a machine which must operate within the restricted limits of mine drifts and, at the same time, provide ample power for the efficient operation of the machine under varying load conditions. The motors must also be insulated to resist moisture and the effect of fumes, and protected against mechanical injury from heavy dust accumulation.

All these conditions have been successfully met in the design of the motors already adopted for this service and, in some of the later types of loaders of small capacity and equipped with caterpillar tractor, all operations have been carried on with only a 2-motor equipment.

The service of these useful machines need not be limited to non-gaseous mines as they can, if necessary, be equipped with explosion-proof motors.

Coal Trimmers

The coal loading pier of the Baltimore & Ohio Railroad Company, at Curtis Bay, Md., was improved by the addition of four electrically-operated trimming machines. This pier is used for loading coal in wholesale quantities into ocean-going vessels. A 10,000-ton boat is sometimes fully loaded in eight to ten hours.

Previous to the installation of these trimming machines, coal was piled by belt conveyors into the open hatches of the boats, and the cargo spaces which were not directly under the hatch were filled by laborers who drew the coal away from the hatch opening with hand shovels.

The trimming machine consists of a flexible and easily controlled telescopic chute

Fig. 39. Coal Trimmer Being Lowered Into Hold of Coal Boat, Showing Method of Depositing Coal from High-speed Belt Conveyor

which can be hung on the ram, on which the main belt carries coal. At the bottom of this chute is a rotating mechanism (Fig. 38) which carries a power-driven conveyor. Coal passes down through the chute, strikes the rapidly moving belt conveyor, and is thrown in any desired direction (Fig. 39) from the open hatch into the cargo spaces of the boat. A trimmer will handle coal at the rate of 100 tons per hour, and will throw it a maximum distance of 50 ft. which is considerably in excess of the working requirements.

The saving in labor effected by this device may be illustrated by a specific instance in which a boat was loaded with 9569 tons of coal in 9 hours and 33 minutes with two machines in service. If hand trimming had been used the labor of 200 men for 25 hours would have been required to complete the loading. In other words, one hour's operation of a trimmer is equivalent to 263 hours' labor of a man, and very arduous, uncomfortable labor at that.

The trimmer is carried from its berth to the end of the ram, raised, lowered, and carried in and out under the control of an operator on the end of the ram. The direction of the speed of the stream of coal is controlled by an operator located with the trimmer in the hold of the boat. All operations are remotely controlled by electric motors and magnetic controllers.

Hoists

An improved type of overhead monorail electric hoist (Fig. 40) was produced, with a normal rating of two tons, in which it has been found possible to increase the capacity to five tons by using four ropes in the same machine. This is accomplished by increasing the motor capacity and the use of special alloy steels in some of the parts where the greatest strength is required.

The driving gear wheels of the trucks are fully protected and those on the hoist run in oil. Special attention has been paid to the

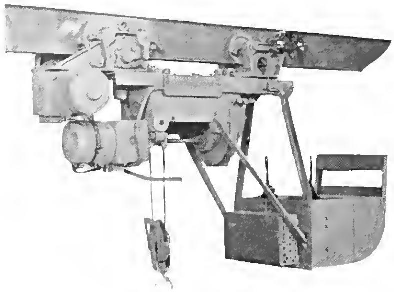


Fig. 40. Two-ton Overhead Monorail Sprague Electric Hoist

electrical wiring and all exposed surface switches have been removed and overload and no-voltage protection provided by magnetic contactors mounted under the operator's seat. Starting and speed control is manual with a large number of steps, but the disconnecting of the circuits for inspection or repairs is accomplished by a protected type snap switch. The operating resistance is set in a ventilated frame in front of the cab. This frame can be opened for the immediate removal of resistance units in case of accident or burn-out, so that there may be the shortest possible interruption of service.

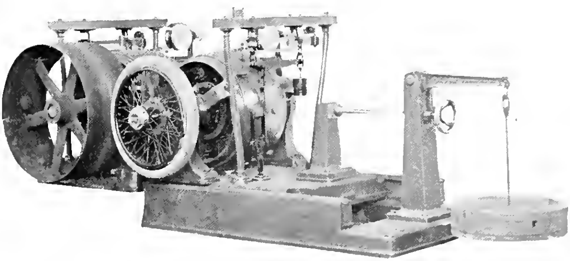


Fig. 41. Testing Automobile Tires by Means of Dynamometer Equipment in United States Bureau of Standards, Washington, D. C.

An important feature of this hoist is the low center of gravity of the motor-driven truck, which improves the riding qualities when negotiating curves and switches. The width of the truck at any part at right angles to the runway is small, enabling the hoist to go

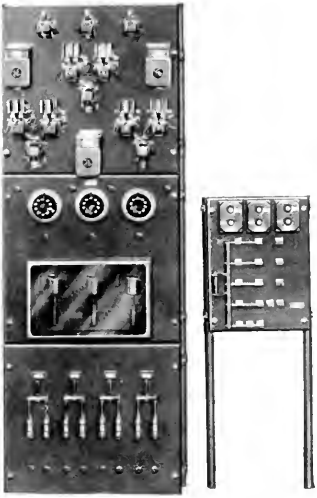


Fig. 42. Electrode Control Panels for Arc Furnace

through narrow switches. The rigid wheel base is short and the trucks are swiveled for negotiating small curves, yet both hoist and cage are suspended from a short frame, so that the overall length is reduced to the minimum consistent with the work to be performed.

Dynamometers

The dynamometer test of automobile tires (Fig. 41) is now coming to be regarded as the correct method of establishing standards of performance, and this test, rather than the mechanical test, will in all probability be generally adopted throughout the country.

The purpose of this test, in which two electric cradle dynamometers are used, is to determine the horse-power loss in the tires under known conditions of pressure, speed, and power transmitted. One of the dynamometers acts as a motor, carrying the tire on its shaft while the other acts as a generator, carrying the drum on its shaft. The pressure between the tire and the drum is obtained by mounting the motor element on a ball-bearing base to reduce the friction to a minimum and lateral pressure is effected by means of weights and levers.

The power transmitted is altered by varying the strength of the current of the generator element, which is absorbed in an external resistor and the slippage is taken by revolution counters. Horse-power input and output are measured with great accuracy from the torque on the dynamometer scales and the speed of revolution.

The losses measured are those arising from the internal friction between the parts of the tire themselves. As is well known, these losses are much less in cord tires than in fabric tires.

Sets similar to the tire-testing set have been constructed for testing belts. Heretofore there has been very little accurate research work done on the capacity and losses of the different types of belting. With these sets an accurate measure can be made of the power at which slipping occurs; the mechanical efficiency of the belt under varying conditions of speed, tension and power transmitted; the best ratio of belt tension for given power transmittal purposes; and the relationship of belt characteristics, method of manufacture, method of tanning, etc., to the load per inch and to the belt efficiency.

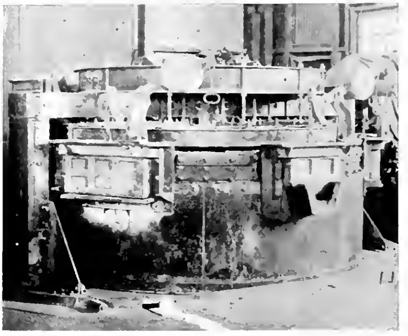


Fig. 43. Induction Type Furnace, Capacity 4000 lbs.

Dynamometers for the testing of centrifugal pumps have been built for operation on both alternating and direct-current circuits, and for very wide ranges of speed. They form a means of measuring the power required to drive centrifugal pumps under all speeds and conditions with much greater accuracy than is possible with the ordinary induction or direct-current motor tests.

It is very much in accord with the spirit of the times that power measurements of this kind should be made with a high degree of accuracy, as the matter of mechanical and hydraulic efficiency of such machinery, while always important, is more important today than ever. An extremely high-speed testing set of this character is now being constructed to be employed in testing pumps which will have to meet the very stringent requirement of the United States Navy.

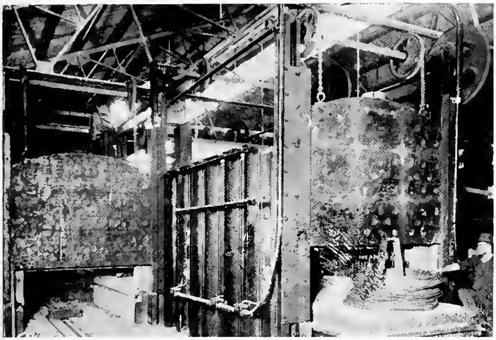


Fig. 44. Compensating Type Electric Furnace for Annealing Steel Wire

Electric Furnaces

The developments in electric furnace equipments were principally along the line of largely increased use—the result of their effect on manufacturing processes in improving the product and in conserving natural fuels because of the economy of electric heating.

The increase in the number of electric furnace regulators (Fig. 42) placed in operation during 1920 over all previous installations was about 25 per cent, a figure that clearly indicates the steadily increasing confidence in this type of furnace when we consider present industrial conditions.

After many years of varying success the induction furnace (Fig. 43) has found a field where it is unassailable. For the melting of large quantities of the same kind of brass day after day, a better average product with less discomfort to the workmen, lower loss of volatile metals and great economy in power consumption, the induction furnace has proved itself to be without an equal.

Another item of engineering and commercial interest is the great possibilities indicated for the super-refining of all kinds of steel, especially the higher grades.

One of the most interesting electrical equipments was that for an electric iron smelting and finishing plant to be installed in Brazil.

Owing to the scarcity of suitable fuel and the comparatively low cost of electric power electricity will be used not only for furnishing power, but also for smelting and refining the steel. That is, the iron ore will be reduced in electric smelting furnaces, the pig iron produced from these furnaces will be converted into steel in electric steel furnaces, and this steel will be rolled into structural and other shapes by electrically driven rolling mills.

It is of interest to note that the power input to these smelting furnaces will be controlled by the combination of a transformer with taps, an induction regulator, and a special motor operated tap changing switch.

This installation will constitute the first commercial electric iron smelting plant on the South American continent, and is undoubtedly the forerunner of future similar developments.

Industrial Heating

A number of new applications of existing types of heating units were made. All of these were for the heating of industrial ovens, and can be divided into two general classes, the first covering low temperature work up to 900 deg. F., the second, high temperature work from 1000 to 1800 deg. F.

An interesting application of the first class consists of the baking of cork tile which is carried on in an oven of standard construction equipped with standard electric oven heating units. The ground cork is moulded into slabs under great pressure and the closed moulds are then passed through a conveyor type electrically heated oven about 70 ft. in length; the current requirements being about 280 kw.

Another application utilizes a temperature of 300 deg. F. for baking furnace lining, the finished product being used for lining in electric furnaces of the induction type.

The first continuous type electrically-heated air tempering oven was also put in service. This is a conveyor type for tempering the races of ball bearings, the oven being divided into two compartments, one directly above the other and the work being carried in through the lower compartment, back to the upper compartment and out. The temperature range is from 250 to 300 deg. F.

In the high temperature field, electric heating was applied to the baking of vitreous or porcelain enamel which requires a heat of about 1600 deg. F.

This particular furnace is divided into two parts, one a preheating chamber and the other a high temperature chamber, each being 4 ft. in length. The first is maintained at a temperature of about 600 deg. F. and the second at 1600 deg. F. This class of work was formerly carried on by means of oil fired furnaces, but the electric heating shows not only a somewhat lower operating cost but the uniform and positive temperature control has resulted in practically no rejections, whereas with the old method of heating, these rejections often ran as high as 20 per cent.

Electric heating was applied for steel wire annealing, a compensating type of furnace (Fig. 44) being utilized for this work. The furnace is divided into two chambers, the heating and the cooling chamber and along side of the latter is a compartment which acts as a preheating chamber. When the wire has been annealed in the heating chamber to the required temperature of about 1500 deg. F. the car is run forward into the cooling chamber and another car is taken from the preheating chamber and run into the heating chamber. This is in turn replaced by a car of cold wire in the preheating chamber so that the heat given off by the load just removed from the heating chamber is absorbed by the cold load. This compensating feature is one of considerable importance from the standpoint of economy, especially if the oven is operated continuously for long periods.

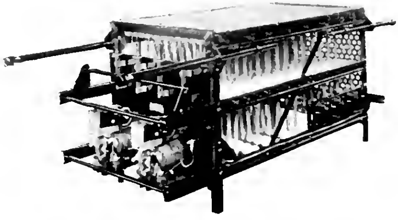


Fig. 46. Portable Arc Welder Resistor Unit with Control Panel

The annealing of brass in the form of rolled strips, drawn tubing, etc., has in the past been carried on largely in wood fired furnaces, or oil fired furnaces using a high grade of oil, the cheaper fuels not being suitable on account of the presence of sulphur in considerable quantities, which acts on the brass and tends to make it brittle. Wood for fuel purposes, of course, is expensive as are the high grades of oil.

During the year a brass manufacturer installed an electrically heated annealing furnace of the metallic resistor type, and while definite operating data are not yet available, it is confidently believed that a superior product will be obtained with a probable reduction in operating cost.

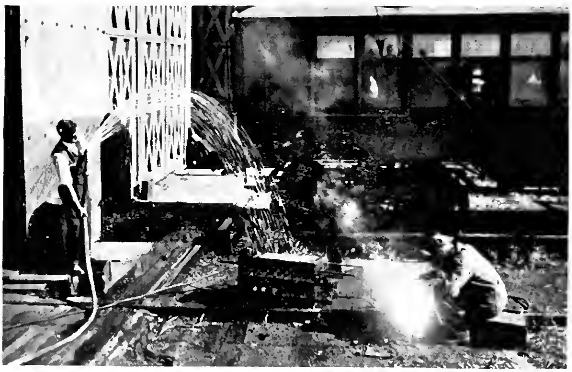


Fig. 45. Testing New Type of Resistor for Arc Welder by Spraying It with Water when It is Operating at Maximum Temperature

Arc Welding

A new type of light weight arc welding resistor was developed for operation on electric railway trolley circuits.

The resistor (Fig. 45) is primarily intended for rail bond welding and track repairs on electric railway systems, where it is necessary to move the welder by hand. This is particularly true of interurban roads and some sections of street railways where the line happens to lie through sections away from the road.

It is designed to deliver current from 50 to 200 amperes, in steps of approximately 15 amperes. The connections are such that by means of a contactor mounted on the panel, and a push button operated by the welders' foot, the electrode holder may be made absolutely dead, thus making it safe to change the electrode. Since the operator holds the push button closed, in case of accidental shock he can clear himself by releasing the push button.

In order to obtain low weight, the resistor (Fig. 46) is designed to operate at a fairly high temperature which will vary somewhat depending upon the conditions of ventilation. The resistance material is nichrome and is unaffected by any temperature at which the resistor may operate. The insulation is a new material which is mechanically and electrically of a very high grade.

As a practical test, one of these resistors was short circuited for about five minutes allowing the parts to reach about the maximum temperature. Cold water was then sprayed on it without causing the least mechanical damage or electrical leakage.

The self-regulating arc welding generator introduced during 1919 is now being used in rapidly increasing numbers due to its inherently valuable characteristics; the increase during 1920 over the previous year being nearly 400 per cent.

The automatic arc welding equipment, which tends to eliminate the human element as far as the quality of the product is concerned, was introduced late in 1919 so that only a few equipments were installed in that year. During 1920, however, approximately sixty equipments of this type were placed in service and, as its possibilities become more widely known, it will very probably be used to a much greater extent.

Research Laboratory

In X-ray work, a new current regulator for the filaments of Coolidge tubes was developed. This device, called a "stablizer," is of great assistance in securing uniform results when the tube is operated from a current source of unstable voltage.

In radio work the development of vacuum tubes in the direction of high power was continued, and the output obtainable from a single tube has been increased many fold.

A new detector tube was produced, which is not only very sensitive but is also very uniform and stable.

Development of the possibilities of tubes other than the pliotron was continued and the dynatron, pliodynatron, and magnetron were each improved and are now available for applications to which their peculiar characteristics adapt them. A modified tungsten filament with high thor a content was successfully introduced with the result of reducing the filament excitation and greatly prolonging the tube life.

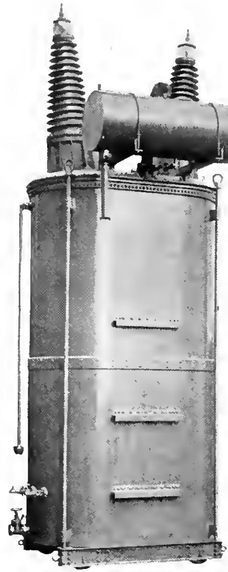


Fig. 47. 165,000-volt, Water-cooled, Outdoor Transformer

The self-lubricating bearing material, "Genelite," was extensively tried out during the year and is now being used in certain parts of automobiles.

A new process for producing a high chrome alloy on the surface of steel was devised and worked on a laboratory scale. Chromized steel resists both rust and oxidation at high temperature.

Transformers

For a number of years the maximum voltage for commercial transmission remained stationary at 150,000 volts, to which point it was carried by the big Creek system of the Southern California Edison Company, but during 1920 the potential was increased to 165,000 volts by means of transformers completed and installed, and there were under construction at the close of the year units for operation on a 220,000-volt line.

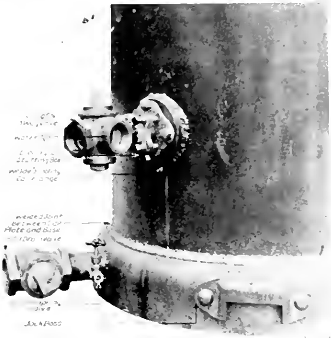


Fig 48. Standard Transformer Tank Showing Arrangement of Jack Boss and Drain Valves

Seven transformers rated at 7500 kv-a., 165,000Y 11,000 volts, 60 cycles were completed for the Great Western Power Company for use on a new transmission system in conjunction with an existing 100,000-volt system. These transformers (Fig. 47) are of the familiar core type construction with concentric high and low voltage windings and are connected in Y although designed for isolated service. They represent the maximum voltage for commercial transformers in actual service.

Four transformers rated at 8333 kv-a., 220,000Y 11,000 volts were under construction for the Southern California Edison Company.

These transformers are designed for grounded Y service and are equipped with only one high voltage bushing, the other end of the winding being permanently grounded to the tank to form the grounded neutral. The completion of these transformers will permit the practical operation for the first time of a 220,000 volt transmission line.

A duplicate of the largest transformer ever built in the United States was completed. It is rated at 25,000 kv-a., 24,000 1200 volts and has an effective output of 50,000 kv-a., and like the original unit, it was produced for the Edison Illuminating Company of Detroit for operation in connection with a 45,000 kw. steam turbine generator. The building of a duplicate transformer of this great size is a sufficient indication of the successful operation of the original unit which in actual service exceeded its high guaranteed efficiency.

Activities in European water-power developments and the consolidation of existing systems there into larger and more efficient systems resulted in a demand for a considerable number of large transformers.

Notable among the consolidations effected is that of the Union Francaise which combines into a single system all of the previous isolated power systems in Paris to supply power in bulk to the existing distribution lines from a single large power station.

For this service an initial installation of six 15,000-kv-a., 66,000 6,000-volt, 50-cycle single-phase transformers was supplied and at present they are the largest units of this type in Europe. For the equipment of the substations on this system, twelve 3125 kv-a., 60,000-volt transformers are being constructed. All of the above transformers are of the water-cooled type.

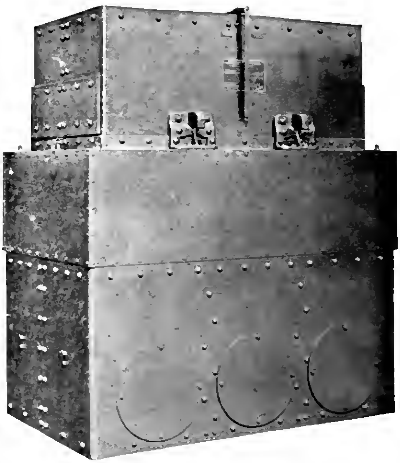


Fig 49. 5600-kv-a., 13,800 6600-volt Air Blast Transformer

Twelve forced oil-cooed transformers rated at 6250 kv-a., 132,000 volts are under construction for a transmission system in Spain.

Among some of the detailed improvements in transformers are a new method of winding the cooling coils, and a new type of stuffing box outlet. These changes have resulted in the cooling coil (Fig. 48) being practically self-draining, and the stuffing box outlet is constructed so that fittings on the ends of the coils do not have to be sprung into place when installing the cooling coil in the tank; furthermore the construction of the stuffing box is such that a leak in the pipe joint from cooling coil to external piping can not result in water getting into the oil in the transformer.

Among the large air blast transformers produced were five 4550-kv-a., 10,900Y/210-volt units for use with synchronous converters for the 3-wire direct-current system of the New York Edison Company. These transformers are of high inherent reactance and are used in conjunction with the synchronous converters without the use of synchronous boosters to obtain the necessary range in direct-current voltage; this voltage range

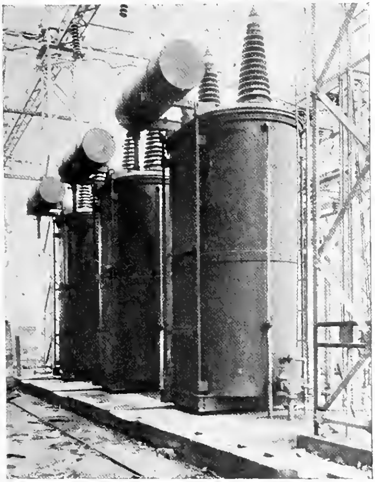


Fig. 50. Typical Installation of Large Oil-cooled Transformers, Showing Use of Oil Conservators

being secured through the compounding characteristics of the synchronous converter in conjunction with the transformer reactance.

Ten 3-phase, 25-cycle, 4600-kv-a. transformers of the same voltage rating were also provided to be used with synchronous boosters and these two equipments operating on the same system will give an excellent comparative operating test of the two methods of obtaining direct-current voltage control.

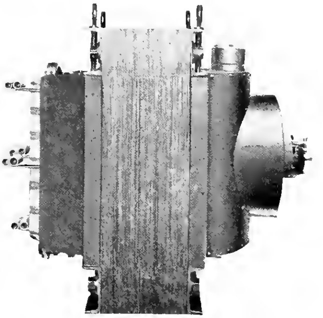


Fig. 51. High Current Air Blast Transformer Equipped with Self-contained Fan

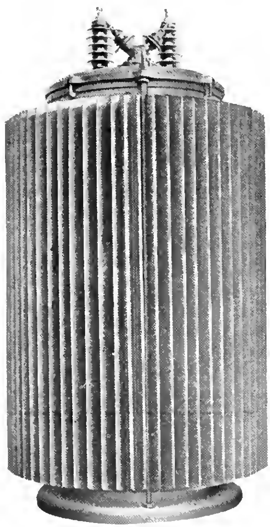


Fig. 52. Round All-steel Transformer Tank with Deep Corrugations

Other air blast transformers under construction included ten 3-phase to 2-phase, $62\frac{1}{2}$-cycle, 5500-kv-a., 13,200 to 5280-volt units and ten 3-phase 62½-cycle, 5600-kv-a., 13,800 to 6600-volt units (Fig. 49).

The operating reports during the year demonstrate the value and the greatly extended use of the oil conservator on large and high voltage transformers. The utility of this feature (Fig. 50) is every day becoming more definitely established by the protection afforded from condensation of water in the transformer oil, the elimination of possible gas explosions due to decomposition of the oil and the gases so produced mixing with air at the top of the tank, and to the practical elimination of sludging of the oil due to its oxidation when in contact with air at fairly high temperatures. It is standard practice now to supply the oil conservator with all transformers over 7500 kv-a. regardless of voltage, and all transformers over 80,000 volts regardless of size. This practice will undoubtedly be extended to include smaller transformers as its advantages become more widely known.

A unique type of high current air-blast transformer was developed (Fig. 51) in which the air is supplied by a fan which is made an integral part of the transformer. These units have capacities ranging from 30 to 250 kv-a. and are suitable for operation on primary circuits up to 2300 volts, 60 cycles.

The low voltage winding consists of solid copper coils interleaved with the high voltage coils. The ends of the low voltage coils are brought out in two parallel vertical rows and a multiplicity of series-parallel connections can be readily made by means of bent copper straps. The fan is operated from a-c. or d-c. circuits of 250 volts and less.

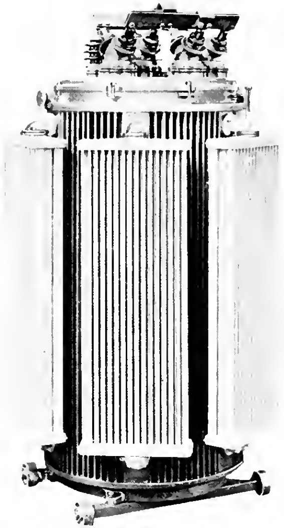


Fig. 53. Outdoor Transformer with Double Conductor Bushings Connected in Multiple

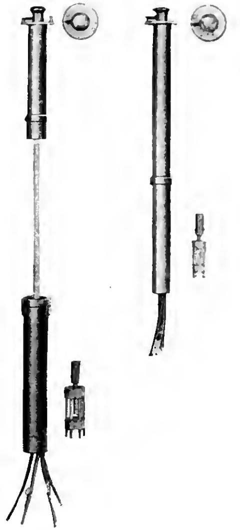


Fig. 54. Radio Adjusters

These transformers are suitable for all requirements for high currents at moderate and low voltages, such as furnaces, welding or high current testing.

For large self-cooled transformers, a transformer tank made entirely of steel with very deep corrugations (Fig. 52) was adopted in order to get a large radiating surface. The use of this tank results in a lighter transformer with no sacrifice in mechanical strength and obviates the necessity of separate radiators on self-cooled transformers of moderate capacity.

An outdoor transformer (Fig. 53) was constructed, designed for 10,000 amperes. This was made possible by using double conductor outdoor bushings in multiple. The leads are brought out non-inductively through the separate bushings and the multiple connection is made outside the cover. By this means an absolutely weather-proof construction is obtained and the non-inductive arrangement of the leads avoids "stray" losses in the magnetic material in the cover.

In addition to the considerable number of large self-cooled transformers completed, there were under construction at the close of the year, three units of exceptional capacity rated 3 phase, 60 cycles, 10,000 kv-a., 27,600/13,800 volts. When completed, these transformers will represent the largest capacity of this type.

A practical and simply constructed device (Fig. 54) for quickly changing regulation taps in a transformer was produced. The change is accomplished by a fractional turn of a handle that is easily accessible from a hand-hole opening in the cover. The handle operates a very simple contact-changing mechanism in the oil, and the change is positively, accurately, and safely made.

The mechanism will withstand any voltage transient or short-circuit that the transformer itself is able to withstand and prevents the operator from making an open circuit or short circuit in the transformer.

To eliminate the inherent troubles due to lamp burnouts on series Christmas tree lighting outfits, a well designed and substantially built toy transformer was produced.

The transformer (Fig. 55) steps the voltage down from 110 to 10, 14 and 24 volts.

When the tree lights are not being used, either of the three (10, 14 or 24) taps can be used to operate electric toys or for other purposes such

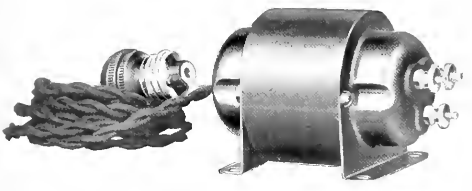


Fig. 55. Toy Transformer

as general ornamental illumination. The capacity of the transformer is 90 watts.

Alternating-current Network Protector

The advantages of ring and network distribution in connection with direct-current systems are well known. The same important advantages, namely, continuity of service and decreased cost of distribution system for given regulation and loss, can be realized in alternating-current network systems supplied by transformers if the transformers are equipped with the a-c. network protector.

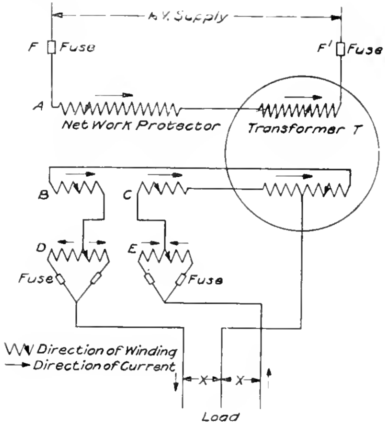


Fig. 56. Connections of Network Protector

The protector is a transformer device with three sets of windings connected as shown in Fig. 56. Two of these windings magnetically oppose each other and the third is arranged so that its magnetic action is neutralized by the division of current, so that when operation is normal there is practically no magnetization of the protector core.

One winding *A* is in series with one of the high tension lines supplying step-down transformer *T*. The second winding of two parts, *B* and *C*, is connected in series with the low tension lines feeding to the network (the neutral of the low tension winding of the transformer *T*, if used, is brought directly to the neutral of the network). The ratio of turns between the two windings *A* and *B-C* is such, and the coils are so wound and connected that the core is not magnetized.

However the low tension current passing through winding *B* and *C* passes into the middle point of the parts *D* and *E* of the third winding. It will be noticed that the current divides in passing through these windings so that the magnetic action of these windings is also neutralized. The ends of windings *D* and

E are connected by fuses to the low tension network. There is no e.m.f. developed in the windings *D* and *E*, since there is no magnetism in the core under normal operating conditions; consequently there will be no flow of current through the local circuits represented by the

Fig. 57. 50-kv-a. Subway Transformer Equipped with Network Protector

windings *D* and *E* and the two fuses connecting the ends of these windings to the network.

Now, should a fault develop in transformer *T* it will draw a very heavy current from the line through fuses *FF'* and protector winding *A*. At the same time a heavy current will be fed back into the transformer from the network through the windings *B* and *C* of the protector. This current is reversed to normal operation so that there is no longer magnetic opposition between windings *A* and *B-C*. The protector core is immediately magnetized and a heavy current flows in the local circuits of the third winding *D* and *E* through the fuses. Even though the high voltage fuses *FF'* are blown, this heavy current through the low voltage fuses continues because of the transformer action between the windings *B-C* and *D-E*. In a very short time interval the circulating current through the fuses blows them and disconnects the transformer *T* from the low tension network. The action of blowing the low tension fuses takes place instantaneously and seemingly simultaneously with the blowing of the primary fuses *FF'*.

The windings of the protector are of very low resistance and consequently the effect on the regulation of the circuit is negligible.

The device has been commercially developed for 50 and 100-kv-a., 60-cycle subway transformers for standard voltages (Fig. 57), and is made an integral part of the transformer.

Power Limiting Reactors

In order to prevent the building up of excessive resonant voltages in systems, particularly where many underground cables of high capacity are used, special shunting resistors were designed (Fig. 58) for use with power limiting reactors.

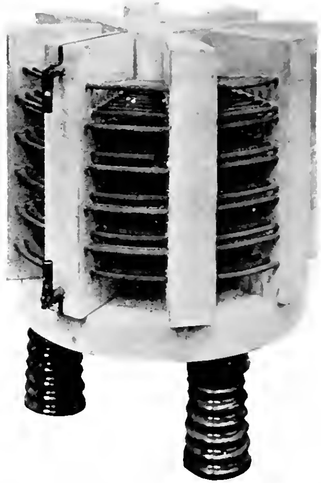


Fig. 58. Current Limiting Reactor Provided with Protective Resistor in the Center

This combination has the property of absorbing the energy of high frequency oscillations thereby preventing their reaching abnormal and dangerous values, and at the same time offers a relatively high resistance to the normal low frequency voltages.

High Voltage Bushings

In the production of the 165,000-volt transformers and the development of the 220,000-volt units it was necessary to design and construct bushings having physical dimensions and dielectric ratings in excess of any hitherto produced for commercial work.

The construction of the first 220,000-volt transformers and oil circuit breakers required the manufacture of the first 220,000-volt bushings intended for actual commercial service. These bushings (Fig. 60) have a maximum A.I.E.E. voltage rating of 250,000 volts at sea level. They are of the oil-filled type.

The upper portion of the bushing, above the cover, consists of two sections of porcelain mechanically bolted together, and the lower portion, below the oil, consists of a single-piece porcelain. It has an average flashover voltage of about 660,000-volts dry, and 445,000 volts wet and receives a one minute test voltage dry of 565,000 volts.

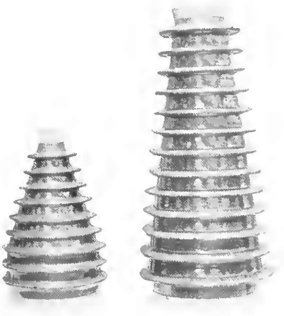


Fig. 59. Bottom and Top Single-piece Porcelains for 165,000-volt Transformer Bushing

Complete interchangeability exists between these bushings as used on transformers and on oil circuit breakers.

In producing the bushings for the 165,000-volt transformers (Fig. 61) it was necessary to make for the upper section of the bushing above the cover, the largest single piece porcelain shell (Fig. 59) ever produced for this class of work. It is slightly greater than five feet in overall length.

This bushing has an average dry flashover voltage of about 520,000 volts and an average wet flashover voltage of about 365,000 volts. Its maximum A.I.E.E. sea level rating is 175,000 volts.

Attention was called a year ago to the standardization of solid type bushings for voltages from 15,000 to 73,000 inclusive, which were interchangeable (Fig. 63) between constant potential transformers, lightning arresters, and oil circuit breakers. This interchangeability of the 400-ampere line of bushings has lately been extended to include current transformers having a maximum rating of 200 amperes, so that these same bushings are now interchangeable between constant potential transformers, lightning arresters, oil circuit breakers, and current transformers of this capacity. The maximum rating of these bushings for constant potential transformers and oil circuit breakers is 400 amperes.

There have now been standardized also two companion lines of bushings for 800 amperes and for 1200 amperes (Fig. 64) similar in general appearance to the 400-ampere bushings, and interchangeable between constant potential transformers, lightning arresters and oil circuit breakers.

A line of triple conductor 7500-volt transformer bushings (Fig. 62) in current ratings up to 2500 amperes was developed.

The bushings are intended primarily for three-phase transformers. They have three separate outlets from the single-piece porcelain shell, and require but one opening in the cover for bringing out the leads from the three phases of the transformer. These bushings, as well as all standard types of solid bushings for power transformers, are suitable for use with oil conservator tanks where the bushings may be subjected to an internal oil pressure.

Switching Apparatus

In general it may be said that the most important developments in switchboards and switching apparatus can be summarized as follows:

There was increased standardization of the apparatus and the manufacturing methods by which it was produced with a resulting interchangeability of parts; switchboards of the latest types either dead front, drawout or truck type can now be assembled to present a homogeneous appearance.

Automatic station control equipment was subjected to intensive study, the result of which has been the production of various standard devices to improve the operating characteristics of these stations.

Drawout panels (Fig. 65) were developed for use in connection with an industrial type oil circuit breaker of ratings up to 300

Fig. 60. 250,000-volt Porcelain Bushing

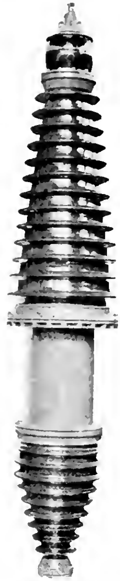


Fig. 61. Type of Bushing Used for 165,000-volt Transformer

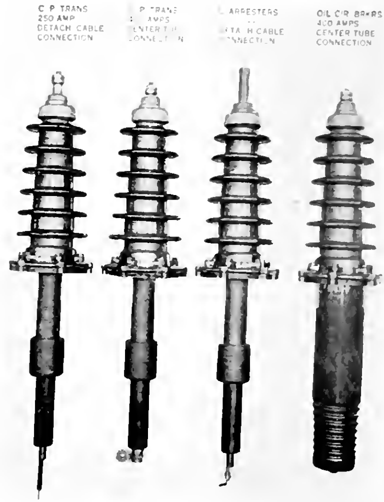


Fig. 63. Interchangeable, High-voltage Bushings with Different Terminal Accessories, Maximum Rating 50,000 Volts, 400 Amperes

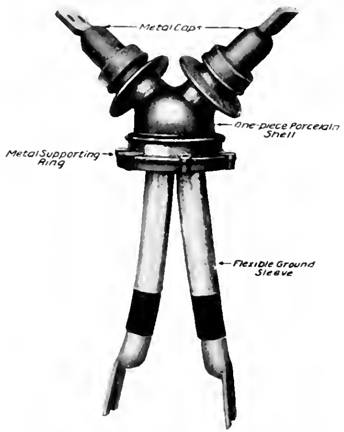


Fig. 62. Double Conductor Bushing Similar in Construction to Triple Conductor Units Recently Developed

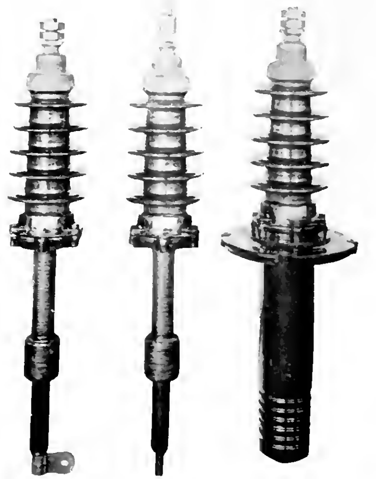


Fig. 64. Interchangeable Bushings. Maximum rating 37,000 volts, 800 amperes

amperes and 3000 volts, which are simple and strong in construction and have all the safety features of the enclosed truck type panel.

These panels also provide a convenient mounting for instruments, meters and instrument transformers required for a typical feeder panel installation of this kind and are particularly suited for industrial installations as they are entirely safe and provide complete enclosure for all the equipment.

They can be installed individually or in groups with continuous bus bars mounted inside of the housings and can also be lined up with truck type switchboard panels.

Fig. 65. Draw Out Panels for Circuit Breakers of Capacities up to 300 Amperes, 3000 Volts

They are made in two forms, one for well mounting where no meters or potential transformers are required, and for floor mounting where meters and potential transformers are required in addition to the usual ammeter equipment.

A new standard line of panels was placed in production during the year for the control of wound rotor and squirrel cage induction motors. They possess several innovations and improvements.

The panels are equipped with nearly all sizes of standard unit types of moderate interrupting capacity oil circuit breakers. The starting breakers are placed side by side back of the main breaker and operated from the front of the panel (Fig. 66) by the usual type of remote control operating mechanism.

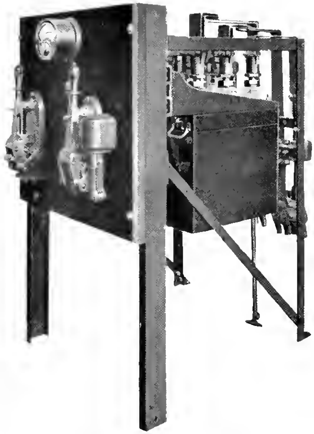


Fig. 66. Standard Panel for Control of 500-h.p. Three-phase Induction Motor

The cable terminals are so located that the main cables can be installed conveniently and run in straight lines without interference with panel parts.

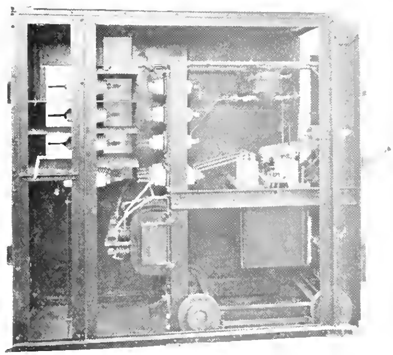
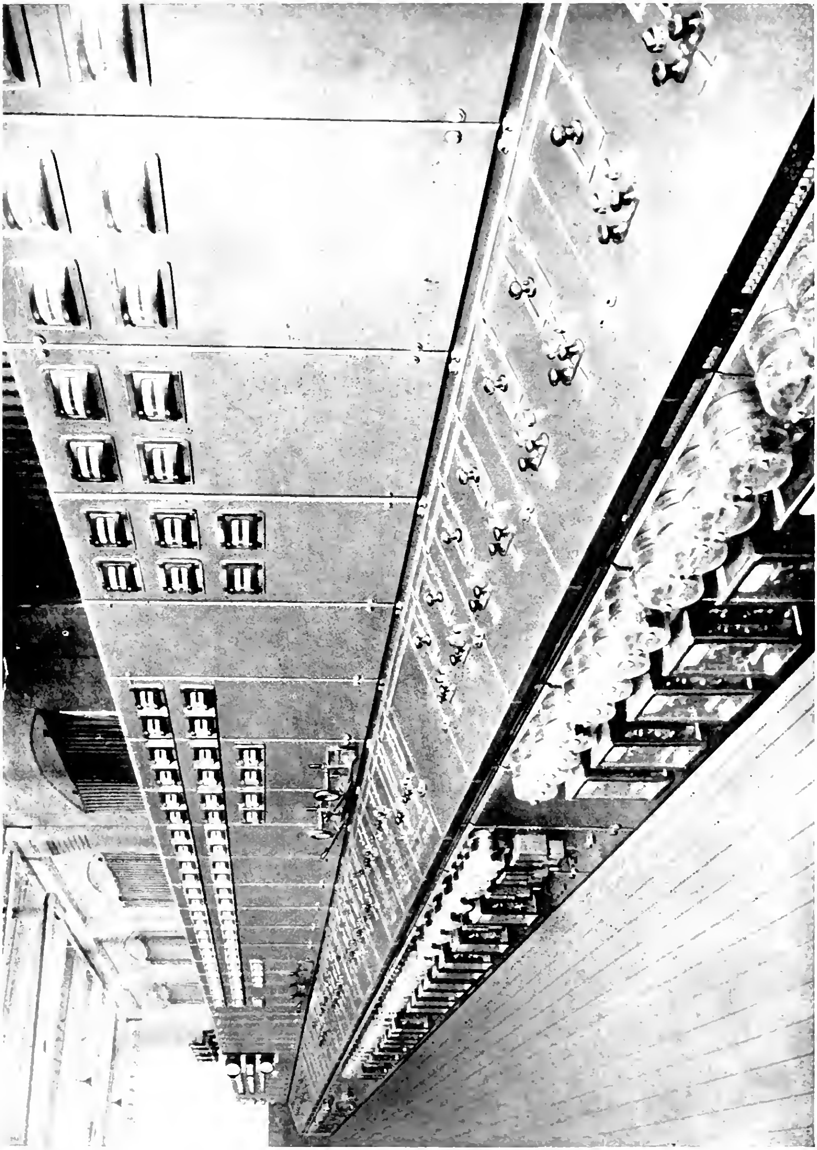


Fig. 67. Removable Truck Type Panel, 4600 Volts 400 Amperes, Showing Truck Partly Withdrawn

When motors are used with compensators without self-contained switches mounted back of the panel, the connections between the compensators and the starting breakers may



An Elaborate Instrument and Control Board for Cape Town, Africa. This switchboard is more than 100 ft. long, and while it controls at present only 20,000 kw. provision is made to handle several times this capacity. It was completed late in 1920, and will be described in an early issue of the *General Electric Review*

Fig. 68. Safety Enclosed Switchboard Made up of Removable Truck Units

be made without undue leveling and without crossing leads.

The panels are unusually well equipped to safeguard the motors, starting devices and switching parts from damage due to abnormal conditions or to carelessness and lack of training on the part of the operator.

The arrangement of the equipment back of the panels makes it a simple matter to obtain complete enclosure by the use of protective wire screens.

The application of the truck type panel (Figs. 67 and 68) has been extended. The upper ratings of feeder panels have been increased both in current and voltage. Generator panels, synchronous and induction motor starting panels, compensator panels and low voltage lightning arrester panels are now available.

In addition to this, considerable progress has been made in simplifying the details of construction, increasing the ease of manipulation and improving the method of installation.

There has been continuous development in circuit breakers, especially the shock proof variety (Fig. 69) resulting in the production of an adjustable time limit trip for breakers of this type up to 2500 amperes.

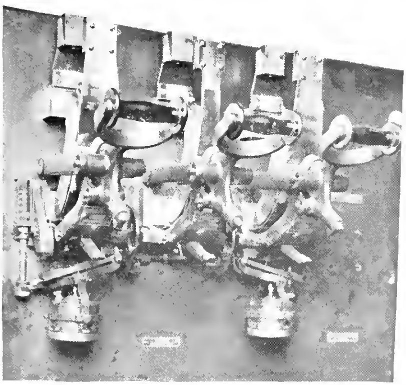


Fig. 69. Inverse Time Limit Overload Air Circuit Breaker, Shock-proof Type

Fig. 70. Solenoid Operating Mechanism for Oil Circuit Breakers Enclosed in Waterproof Case

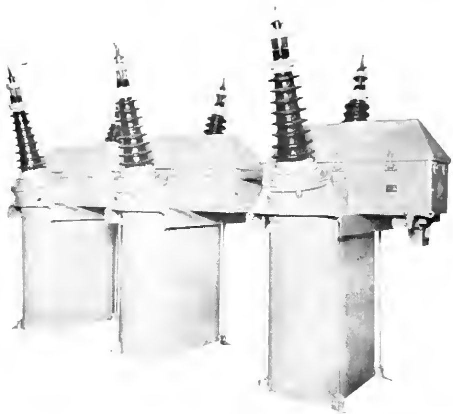


Fig. 71. 95,000-volt, 400-amp., Triple-pole, Single-throw Oil Circuit Breaker

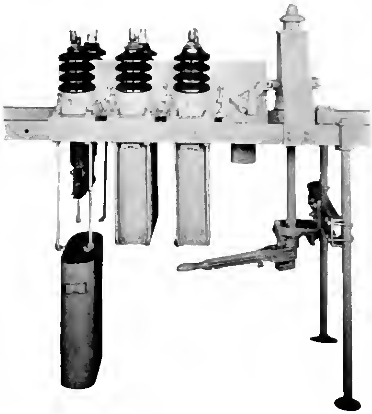


Fig. 72. 15,000-volt, 400-amp., Oil Circuit Breaker for Outdoor Pole Mounting

For somewhat special applications of three-wire systems, double and triple pole breakers were equipped with electric locks and under-voltage devices. Also double-pole breakers were provided with a neutral coil to open the breaker in the event of too great over balancing.

A new type of magnetic blowout was designed for use in connection with direct-current air circuit breakers of 1500 volts and above.

This blowout has the advantage of simplicity in construction, ease of repair and replacement of parts, and very effective action even when rupturing currents below the normal rating of the breakers.

This latter effect has always been more or less difficult to obtain at high voltages, but the new unit is very effective, not only under heavy load, but because of the improved design it will also handle the low currents effectively.

All solenoid operated oil circuit breakers, whether for indoor or outdoor service, are being equipped with a type of solenoid recently developed. For outdoor service (Fig. 70) the solenoid is enclosed in a sheet metal housing.

In the new solenoid all the operating mechanism is mounted on a removable head which is the same for all capacities. The solenoid pot, that is, the portion which carries the armature and winding, is varied to suit the requirements.

When more power than can be obtained with one solenoid is required, an additional solenoid (without head) is mounted underneath the first one so that the top of the plunger of the lower solenoid pushes against the lower surface of the armature of the upper solenoid to increase the operating power.

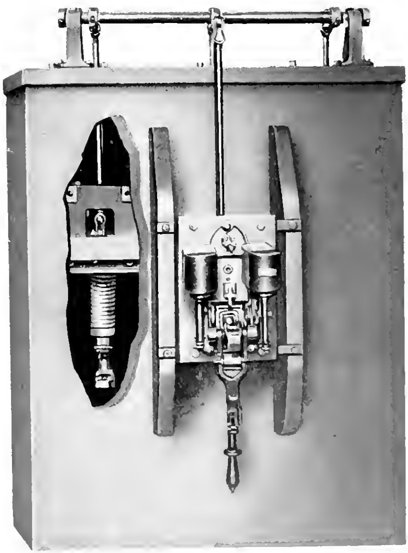


Fig. 73. Arrangement of Oil Circuit Breaker Mounted in Solid Concrete Cell

This standardization makes it possible to meet a great range of operating conditions with but few mechanical parts, simply by changing the operating coil in the pot of the solenoid.

The line of high pressure, high interrupting capacity oil circuit breakers has been extended to include units of 220,000 volts.

The breakers for use up to 73,000 volts are arranged for mounting on the floor or on a framework high enough to allow the lowering and removing of the oil tanks with the contacts open. For voltages of 95,000 and above (Fig. 71) the breakers are either installed on the floor or on steel girders which rest on concrete foundation pedestals.

A new oil circuit breaker for outdoor pole mounting (Fig. 72) possesses several characteristics never before included in a breaker for this service. It is built in 15,000 volt, 400 ampere capacity only and is manually operated.

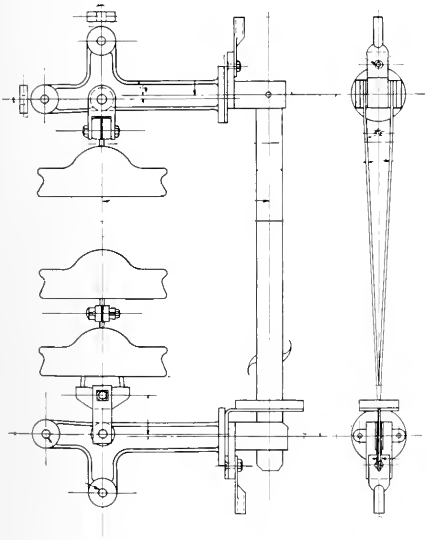


Fig. 74. Disconnected Switch, Showing Use of Hewlett Suspension Insulators

It is of standard unit construction and the blades, contacts and tanks are interchangeable with one of the standard unit type oil circuit breakers of the same capacity.

The bushings are of the same type as those used in large outdoor oil circuit breakers of high interrupting capacity and the connections to the line are made at the upper extremity of the bushings and not inside the cover as in the usual construction.

The breaker is tripped out automatically by means of a trip coil operated by bushing

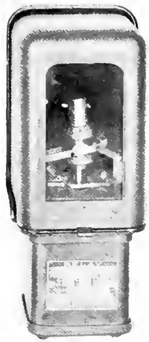


Fig. 75. Instantaneous Circuit-closing, Alternating-current, Under-voltage Relay

Fig. 76. Time-limit Circuit-closing, Alternating-current, under-voltage Relay

transformers, an indicator tells whether the switch is in the open or closed position, and a bell alarm switch closes when the breaker opens.

The latest design of disconnecting switch for mounting in a transmission line is shown in Fig. 74. The main feature is the use of Hewlett strain insulators and the method of mounting which prevents the insulation from breaking down even from a crack in the insulators. This type of switch is very dependable and a valuable addition to the line of outdoor disconnecting switches.

A new alternating-current undervoltage relay has various applications but is used mainly in connection with automatic oil circuit breakers to trip out the breakers in the event of cessation or predetermined drop of voltage of a certain time duration.

The relay is self-setting and arranged for instantaneous pick up, and instantaneous (Fig. 75) or time limit (Fig. 76) closing of the tripping contacts.

Thus the apparatus protected by the relay will not trip out on momentary surges on an undervoltage which lasts for a time less than the setting of the relay. The use of a time limit undervoltage relay in this way prevents

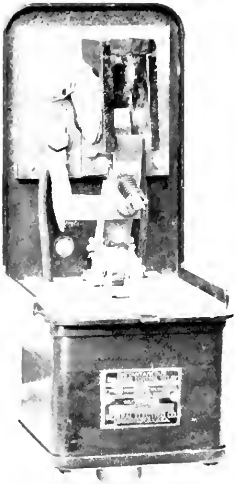


Fig. 77. Solenoid Control Relay Provided with Magnetic Blowout for the Contactors

Fig. 78. Self-setting, Under-voltage Device for Solenoid-operated Air Circuit Breakers

the tripping of a breaker on momentary drops in voltage.

A new type of solenoid control relay (Fig. 77) was developed which possesses features that will make it feasible readily to replace the present types of solenoid control relay. It can be made either instantaneous opening or hesitating in action and has the same general appearance in either type. In fact the same frame is used.

The distinguishing feature of this relay when compared with the former types of solenoid control relays is that a cover is placed over the contacts. There is also provided a magnetic blowout for the contacts which will fill the need for an enclosed contact type of solenoid control relay—a thing which has been often called for by users of these relays.

A compensating relay has been developed which is capable of working up to a speed of 65 words a minute which is the limit of speed of hand sending. This relay is used to put more or less resistance in the secondary of the induction motor which drives the generator of the 200-kw. wireless set, depending upon whether the load is off or on.

The main point of interest in the relay (Fig. 79) is that the contacts are built to open from 150 to 200 amperes at approximately 250 volts at any speed up to 15 operations a second. The amount of current actually broken however will depend on the size of the generator and the arrangement of the circuits.

The relays are usually used in sets of three, and by means of a motor-driven blower an air blast of approximately 2 lb. pressure is

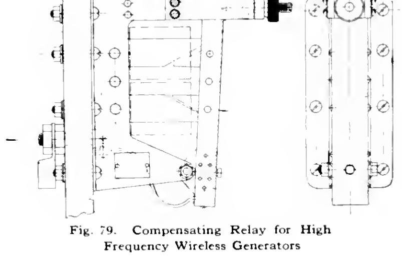


Fig. 79. Compensating Relay for High Frequency Wireless Generators

maintained constantly across the relay contacts to assist in blowing out the arc very quickly and thereby helping to prolong the life of the contacts.

A self-setting undervoltage device (Fig. 78) for use with solenoid-operated air circuit breakers from 2000 to 6000 amperes capacity was produced.

This device is of the hinged armature type. When the armature falls, the breaker is tripped and the opening of the breaker returns the armature of the undervoltage device to the closed position where it is held mechanically from the fact that the breaker is open and when voltage is restored the armature is then held magnetically so that the breaker if closed will remain closed, as the pressure on the line is greater than the tripping point

Automatic station control equipment developments tended toward standardization as the result of the experience gained in the design, application, installation and operation of over 100 equipments.

Standard equipments were designed to meet a wide variety of service. They are now available for synchronous converters (Fig. 80), synchronous motor-generator sets, induction motor-generator sets, synchronous condensers and small waterwheel-driven generators and they may be applied to railway, lighting, power, industrial and mining service.

Device developments for automatic stations were principally in the nature of perfecting existing designs. Relays were made more reliable and now require very much less attention than in the earlier stations. Oil circuit breakers were provided with an a-c. motor operated mechanism which has eliminated many minor troubles experienced with some of the earlier applications.

Some new devices were developed to meet new conditions. One of these is the multi-pen recorder which shows the operation of all the principal devices in the automatic control equipment and relates these to the load fluctuations. It gives an automatic log of the station in very much better form than the log which is found in the usual manually-operated station.

Automatic a-c. and d-c. feeder equipments may now be considered semi-standard. as the developments during 1920 were such as to bring them to a stage of improvement where they are now applicable to many types of service.

Lighting

The number of large incandescent lamps sold in the United States during 1920 totaled about 231,000,000. Of this amount about 215,000,000 were tungsten filament lamps and 16,000,000 carbon filament lamps. This means that 93 per cent of the lamps sold were tungsten filament lamps. According to these estimates (Fig. 81) the large lamp business of 1920 represents an increase of 25 per cent over 1919.

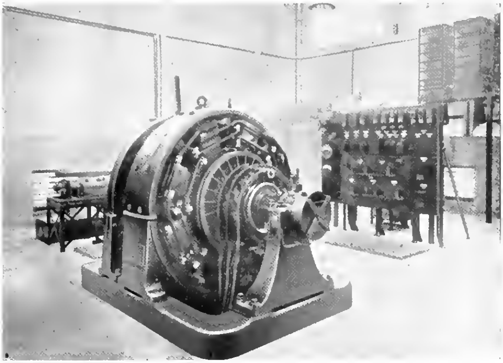


Fig 80. Automatic Railway Substation Equipped with Synchronous Converter and Automatic Control Equipment

Very few marked innovations in incandescent electric lamps appeared during the year, but there was a great deal of development work done, the results of which were largely evident as refinements in quality rather than as striking changes in design.

An immense amount of experimental work was done on the Mazda picture lamp as well as on apparatus designed for use with it. Hundreds of trial installations were made and are now being watched very carefully in order that flaws in either the lamp or the apparatus may be detected and remedied. A very important change was made in the mechanical construction of this lamp which results in increased life and improved candle-power maintenance during life.

Material progress was achieved in the standardization of voltages (Fig. 82) as information available indicates that 79 per cent of incandescent lamps sold in 1910 will be used on either 110, 115 or 120 volts as compared with 45 per cent of lamps used on those voltages in 1913. Inasmuch as practically all central stations, electrical manufacturers and dealers are in favor of the standardization of circuit voltages, it is to be hoped that rapid progress will be made this year and that this problem will be given serious consideration by all those interested until standardization of 110, 115 and 120 volts will be completely effected.

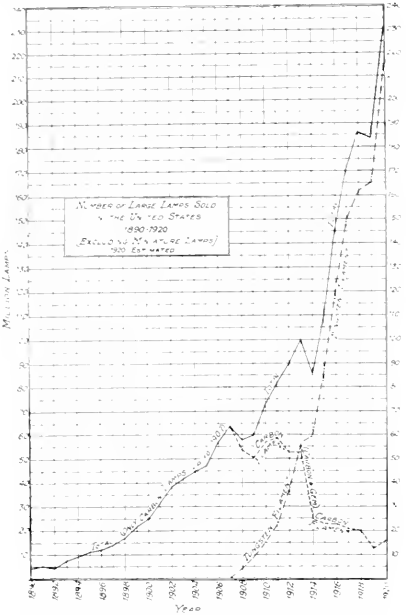


Fig 81 Number of Incandescent Lamps Sold in the United States—Excluding Miniature Lamps

The production of tubular Mazda stereopticon lamps to replace round bulb lamps was accomplished and apparently these lamps will be largely made in the tubular bulb form in the future.

A new shape bulb (Fig. 83) was put in production for Christmas tree lamps. The coloring matter is of a new type, translucent rather than transparent, rendering the location of the filament invisible. The efficiency of the lamp was also increased somewhat, giving the light more snap and sparkle.

The high cost of labor caused the railroads to take up actively the electrification of their present lighting signals and the oil flame in the signalling lantern has to a considerable extent been replaced by a miniature lamp. Where power is available, 10-volt lamps are usually supplied through transformers. Along the lines where power is not available, $3\frac{1}{2}$-volt lamps are operated either from storage batteries or more generally by primary batteries. By an ingenious arrangement, the lamps are operated only when a train is approaching.

The cost of maintenance of the electric signal (Fig. 84) is less than one fifth of the cost of an oil signal per year and has proved to be more reliable and gives a more brilliantly colored signal. It seems probable that the old style oil flame signal will soon be a thing of the past.

A closer filament concentration in Mazda C automobile headlight lamps is now being obtained which permits a more accurate focusing and produces a better distribution of light in the beam.

During the last six months of 1920 much work was done in studying automobile voltage conditions in actual service. These tests were carried on with many makes of cars, both old and new, and as a result of this investigation some changes will be made in the voltage of various automobile lamps, resulting in increased efficiency and higher brilliancy.

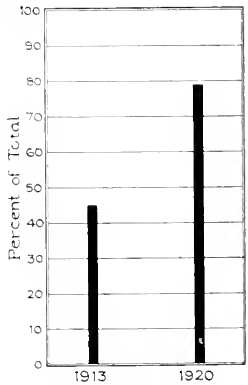


Fig. 82. Comparison of Demand for 110, 115 and 120-volt lamps in 1913 and 1920

The number of lamps on the standard schedule has been materially reduced and soon a few lamps will cover the general automobile lighting field with the elimination of many specialties now in service.

Due to the war a powerful impetus was given to surgical and dental instrument lighting and the demand for miniature lamps for this class of service is constantly increasing.

A new type of flashlight (Fig. 85) appeared on the market consisting of a set of permanent magnets rotated by a chain and ratchet past some coils of wire. Electric current is thus generated without the necessity of a battery and outside of the possibility of lamp failure it is always ready for use.

With the advent of the foot-candle meter illumination measurement at once progressed from an expert operation to one which can be made with reasonable accuracy by a layman. Industrialists as well as merchants, state departmental inspectors and others are now beginning to prescribe their own lighting in terms of foot-candles.

About four thousand of these instruments have been sold in the last two years and several hundred a month are now being put out. The general knowledge of illumination quantity on the part of light users is certain to result in a betterment of lighting practice in accordance with individual needs.

To meet the demand for measurement of higher intensities, the range of the foot-candle meter has been raised to an upper limit of forty in place of twenty-five foot-candles. At the same time more leeway has been allowed for the voltage depreciation of the dry battery supplying the standard lamp. A reflector has been placed behind the lamp and a blue screen introduced which makes the light blend in color more nearly with that of the Mazda C lamp.

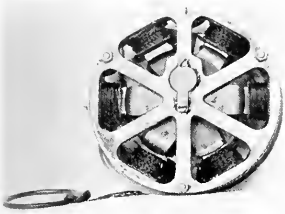


Fig. 84. An Oil Lantern in which the Oil Lamp Has Been Replaced by a Mazda Lamp for Railway Signal Service

Fig. 83. New Miniature Lamp for Christmas Tree Lighting

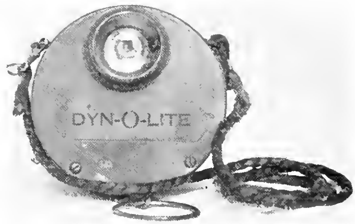


Fig. 85. A Mechanical Flashlight which Does Not Require a Battery

Since the war there has been a remarkable stiffening in the demand for quantity and diffusion of illumination in various artificial lighting applications. Intensities that would have seemed extravagant a few years ago are being found economically advantageous in 1920. Likewise more effort is being expended to eliminate glare.

In their effort to minimize the brilliancy of the light source and thus improve the illumination from Mazda C lamps in open reflectors the lamp manufacturers have standardized bowl enameled lamps in which the lower half of the lamp bulb is coated with mineral material of rather higher diffusing quality than the frosting previously provided.

A considerable amount of faulty illumination is due to improper attention to cleaning. A very thin layer of dirt on lamps and reflecting equipment materially reduces the light output. Engineers have realized this for a considerable time, but until recently have not made as much effort as is desirable to impress this fact on the minds of the public.

During the past year considerable publicity was given to the subject, data obtained from tests were called to the attention of operating departments, and every effort made to see that proper cleaning of equipment is made the practice.

Fig. 86. Permanent "Better Industrial Lighting" Demonstration. The apparatus for demonstrating the various types of reflectors, speed of vision, color of light and allied subjects will be noted at the front of the room. The lighting units used for the various systems are attached to the ceiling, while the means for changing the color of the walls will be noted at the sides of the room

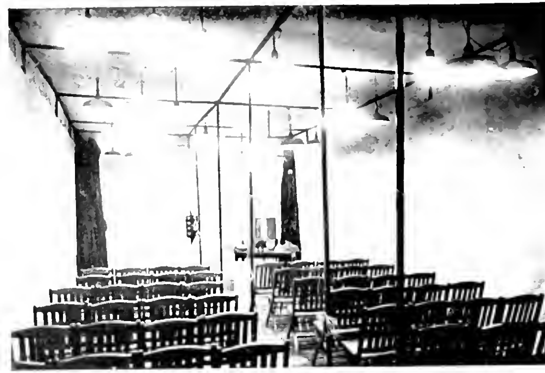


Fig. 87. Portable "Better Industrial Lighting" Demonstration. A canvass covering is supported on a knock down pipe framework. Black curtains are used to change the character of wall finish. The lighting units are suspended from the framework and controlled from a switchboard at the front of the room. The demonstration apparatus will be noted on the lecturer's table

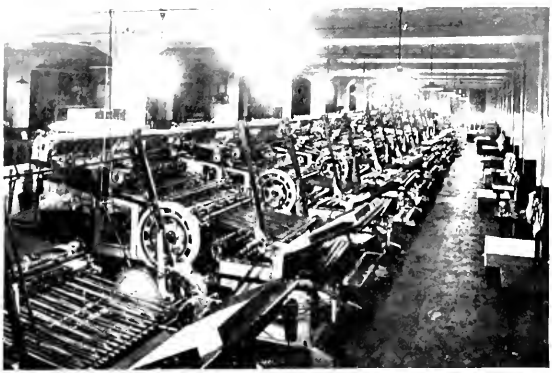


Fig. 88. Localized General High Intensity Lighting as Applied to a Modern Printing Plant. The white enamel finish of the machinery is worthy of special comment, introducing an element of diffusion in the illumination and eliminating sharp shadows

Fig. 89. General Illumination Applied to an Up to-date Shoe Factory. The treeing operation is carried on in this particular department. With high intensity illumination fewer "cripples" (i.e. seconds) result. A greater production is obtained and the plant is more sanitary and cheerful

Dark surroundings make an interior gloomy and disagreeable no matter how much light is supplied. With any system of illumination (Fig. 86) a considerable part of the flux will strike the walls and ceilings. If these have a relatively high coefficient of reflection, the overall effectiveness of the system will be of a higher order. On this subject also stress has been laid and information on the reflecting properties of various kinds of paint disseminated.

At the 1920 convention of the Illuminating Engineering Society a well known psychologist reported tests which seem to confirm the practical experience, that the higher intensities of illumination not only increase visual power but very materially quicken it.

In addition, these tests indicate that astigmatic, aged and otherwise sub-normal eyes are benefited in these respects considerably more than normal eyes.

The year 1920 stands out as one in which the advantage of high level illumination for industrial plants has received remarkable support as a means of increasing the rate and economy of production. Responding to this interest, the lamp manufacturers developed the demonstration method of illustrating modern practice and its effectiveness. Special demonstration rooms were constructed in Cleveland, Harrison, Chicago and at Association Island. Such a demonstration at the Pasedena Convention of the National Electric Light Association resulted in this Association undertaking a nation-wide campaign of education. More or less permanent demonstrations have been erected in Baltimore and New York, while others are under way in Boston, Philadelphia, San Francisco, Los Angeles, Cincinnati and other large cities.

Supplementing this, the lamp manufacturers and central station syndicates are exhibiting portable demonstrations (Fig. 87) in smaller places and in connection with industrial conventions.

It has not been definitely determined where the economic limit of high level illumination lies. Even though our concepts have been considerably raised over those of a few years ago, it is probable that it may prove desirable to go somewhat higher. At the present time intensities between ten and twenty foot-candles general illumination are being supplied where two to four foot-candles was formerly standard practices. Daylight intensities in interiors run as high as several hundred foot candles while out of doors they are as high as eight thousand foot-candles.

In a number of industries local lighting has, in the past, been more common than general or localized illumination. The advantages of modern lighting methods have apparently never been brought to the attention of the industries as a whole. Some of these industries (Figs. 88, 89 and 90) have recently been investigated with a view to ascertaining their lighting demands and the

Fig. 90. The Switchpoint in a Coal Mine, with Suitable General Illumination. It is very interesting to contrast this picture with conditions as usually encountered in the mine. It is no wonder that the accident rate is relatively high considering the dangerous operating conditions and the total inadequacies of the lighting as ordinarily supplied

best methods of meeting them. Among these might be mentioned textile mills, shoe factories, coal mines, printing plants and grain elevators. The information obtained from these investigations has been dissemi-

Fig. 91. Typical Mirrored Glass Window Lighting Reflector with Gelatin Color Screen and Holder in Place

nated and presented in the technical press as well as manufacturers' bulletins.

There has been a growing appreciation of the necessity of accurate north light for color comparison. Research has developed suitably toned glass screens for modifying the light from the Mazda C lamp to this quality. Units embodying this principle have been widely distributed throughout industrial

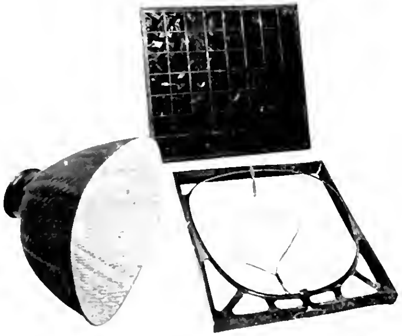


Fig. 92. Standard Show Window Reflector with Color Screen, Color Screen Holder and Supporting Harness. Exploded View

plants where color determination is an important element of manufacture and in retail and wholesale establishments in order that the customer may select his goods with confidence.

With the realization that the show window is a miniature stage, the display man has begun to adopt the stage lighting methods to the window. Instead of confining his efforts to the use of unmodified light, toned or tinted general illumination has come into widespread use. On the stage, the spotlight is employed to bring out particular objects or actors to the special attention of the audience. Small spotlights of the suspension type and footlight type employing concentrated filament Mazda lamps together with color screens are now used in the show window.

The Fifth Avenue Association of New York City last spring set aside a special week in

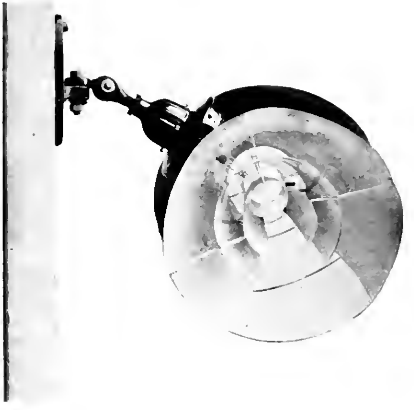


Fig. 93. Double Reflector Unit for Highway Lighting

which particular attention was paid to window displays and exhibits. As an introductory element, the prominent merchants together with their display men were given a talk and demonstration on the possibilities of color and directional effects in show window lighting. The principles outlined were embodied in many very interesting and attention compelling displays.

Much interest in the subject was evidenced at the last convention of the International Association of Display Men where talks and demonstrations were presented. At the suggestion of the illuminating engineers of the lamp manufacturers, a leading reflector manufacturer devised an equipment (Figs. 91 and 92) whereby gelatine color screens can be con-

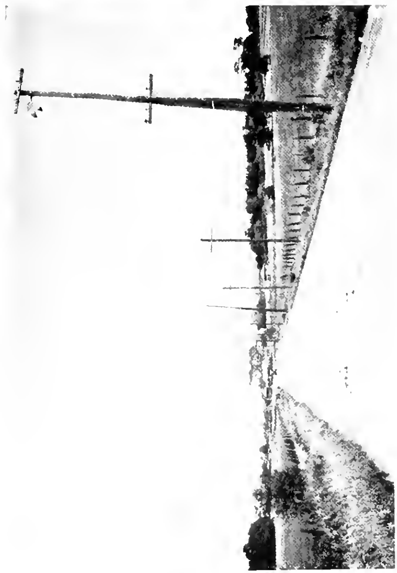


Fig. 94 Arrangement of Highway Reflectors on Telegraph Poles Alongside of Road

Fig. 95. Highway Illumination by Double Unit Reflectors

Fig. 96. Broadway, Los Angeles, Cal., Lighted by 6.6-ampere Luminous Arc Lamps

Fig. 97. Night View, Saratoga, Springs, N. Y., Showing Illumination with Duoflux Incandescent Lamp Lighting Units

[illegible]8. O[illegible] Standard for [illegible] Broadway, [illegible]

veniently attached to the openings of the standard show window reflector and changed at will.

Investigations by horticultural experts have indicated that the periods of budding and ripening of plant life are controlled by the hours of daily exposure to light. Other qualities are affected by the intensity. Light control is therefore offering possibilities for meeting economic needs of certain classes of fruit, flower, and vegetable production.

The ruling of the Interstate Commerce Commission has gone into effect with the result that all road locomotives have been equipped with 250-watt incandescent head lights usually supplied with current from small steam turbines. The excellent lighting effect has been plainly evident.

The Associations of Fixture Manufacturers and Lighting Fixture Dealers held what was known as a fixture market in Detroit during the year. At this meeting new designs were displayed and developmental work discussed. A meeting is planned for Buffalo during the present year. This will be on a more elaborate scale than heretofore and a "better lighting week" on which all the electric interests of the city will co-operate, is contemplated. Talks will be given to local organizations and educational demonstrations are a part of the program.

For some years past there has been felt a growing need for the illumination of highways beyond the limits of cities and towns due to the growth in traffic caused by the increasing use of motor cars for interurban bus lines and freight transportation in addition to the greater density of pleasure vehicle traffic.

The lighting units heretofore selected for this service have been equipped with reflectors

Fig. 99. Ornamental Duoflux Lighting Standard for Broadway, Saratoga Springs, N. Y.

which caused a considerable portion of the light to be wasted by illuminating the area on either side of the road and in order to secure adequate illumination by this means it was necessary to have the lighting units closely spaced thereby rendering the project exceedingly expensive.

After a considerable amount of experiment with a number of special reflector units installed for long periods under typical highway conditions, a double unit reflector (Fig. 93) was designed so that the light from a single incandescent lamp is projected in both directions along the road, and effective illumination of the roadway can now be secured with very wide spacing (Fig. 94) of these units.

The complete unit can be readily installed on existing telegraph or other poles lining the highway and each half of the unit consists of three parabolic nested reflectors which prevent the escape of the light beyond the sides of the road and project it lengthwise in both directions.

In order to secure illumination directly beneath the unit, the reflectors have V-shaped openings in the bottom, which permit the projection of a portion of the light rays directly on the road beneath the pole.

The experimental installations (Fig. 95) of this unit have given every indication that the problem of securing adequate economical highway illumination without objectionable glare has been solved.

Two important street lighting systems were completed and placed in operation during the year, one of these being in Los Angeles, California, where luminous arc lamps are used, the other being in Saratoga, N. Y., where incandescent lamps are used.

The system on Broadway, Los Angeles (Fig. 96), was lighted January 17, 1920, there being 134 2-light ornamental standards (Fig. 97) utilizing 6.6-ampere luminous arc lamps. Sixty-seven of these lamps burn all night, the remainder being extinguished at midnight.

It is interesting to note that in general the luminous arc lamp business of 1920 showed an increase of more than fifty per cent over that of 1919.

The Broadway system at Saratoga Springs, N. Y., was placed in service June 19, 1920, and represents the highest intensity of illumination so far used for incandescent street lighting. Each of the ornamental standards (Fig. 98) is equipped with two duoflux units, each of which contains one 1000-candle-power and one 250-candle-power series Mazda lamp. The larger lamp in each globe is extinguished at midnight, at which time the smaller one is lighted. This arrangement permits the use of reduced illumination of a uniform intensity after midnight without a duplication of lighting circuits.

Seventy of these standards have been used (Fig. 99) for lighting nearly a mile of street.

Commercial Photometry

PART II

By A. L. Powell and J. A. Summers
Edison Lamp Works, General Electric Company

Part I of this article appeared in our December issue, treated of the methods of comparing and measuring light, described the photometric devices employed, and gave instructions as to the calibration and test manipulation of these devices. The foregoing information is in this concluding installment directly applied to the various commercial types of photometric testing. Such include the measurement of illumination, brightness, and reflection factors in interiors of different character, street lighting, and projector illumination. A very useful bibliography is appended. Editor.

Illumination Tests

It is often desirable to determine the average illumination on a certain horizontal plane in a given room and from the values obtained to calculate the coefficient of utilization of the particular equipment under the special conditions.

For this work one of the portable photometers is employed with the test plate fixed in a horizontal position at the specified distance above the floor. The room is divided into sections and readings taken in the center of each section. Two or more readings should be taken at each to insure accurate results.

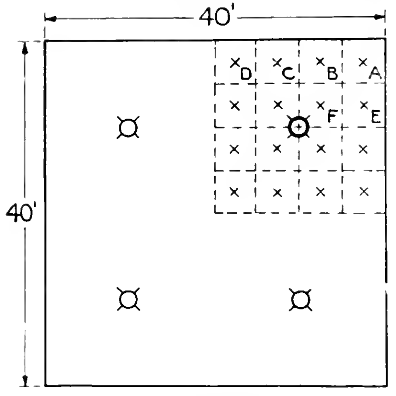


Fig 14. Location of Test Stations for a Symmetrical Room

The choice of stations will depend on a number of factors. If the room is symmetrical, having all four walls of approximately the same characteristics, an exploration of one quarter of the room will be sufficient for the purpose as indicated in Fig. 14, for there will be a corresponding reading in each of the remaining quarters of the room.

If the room has one wall of comparatively high reflecting power and the opposite wall is largely composed of windows it will then be desirable to explore one half of the room as indicated in Fig. 15, each of the stations being duplicated in the other half.

If a very large area, as for example an industrial plant, erecting shop, or foundry, is to be tested, a typical section as indicated in Fig. 16 may be explored.

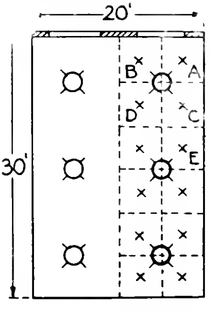


Fig. 15. Location of Test Stations for an Unsymmetrical Room

The first step of procedure is to lay out the stations as indicated and determine the illumination at each of the stations (Figs. 17 and 18) and a simple arithmetical calculation will give the average illumination.

In connection with the test, the following points should be recorded:

- Floor plan showing test stations and lighting outlets.
- Color of floor.
- Color of walls.
- Color of ceiling.
- Height of ceiling.
- Height of lamps.
- Voltage.
- Wattage and rated lumens of lamps.
- Type of reflector or globe equipment, including trade name and dimensions.
- Voltage of circuit.
- Average illumination.
- Minimum illumination.
- Maximum illumination.
- Ratio of minimum to maximum illumination.
- Total generated lumens.
- Total effective lumens.
- Coefficient of utilization.
- Special remarks.

Also, the following conditions should be complied with:

Make sure that the tester or observers do not cast shadows on the test plate.

Be sure, at all times, that the current or voltage flowing through or applied to the comparison lamp in the portable photometer corresponds to the calibration values.

Keep the test plate level on the horizontal plane.

If the voltage of the lighting circuit is different from that of the lamps all readings must be corrected to standard values. For example, the lamps used are rated 115 volts and the circuit voltage is found to be 112 volts. In other words, the lamps are operating at 97½ per cent of normal voltage. From a suitable curve it will be seen that they are giving 92 per cent of their normal candle-power or lumens. All readings must therefore be multiplied by 1/0.92 or 1.07. If the voltage is fairly constant, a reading taking at the beginning, at the middle, and at the conclusion of the test will be satisfactory. If the voltage fluctuates rapidly and accurate results are desired, simultaneous readings of illumination and voltage must be taken. A condition such as this is encountered when testing the illumination in a street car operated from the trolley circuit.

Illumination readings are ordinarily taken on the horizontal plane. In the office, drafting room, factory or shop, at the desk or bench level. In an armory, a gymnasium, depot or similar place, readings should be taken at some arbitrary elevation, usually 30 in. above the floor; in stores at the counter

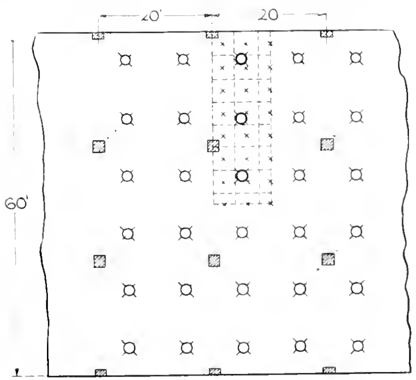


Fig. 16. Location of Test Stations in a Large Area

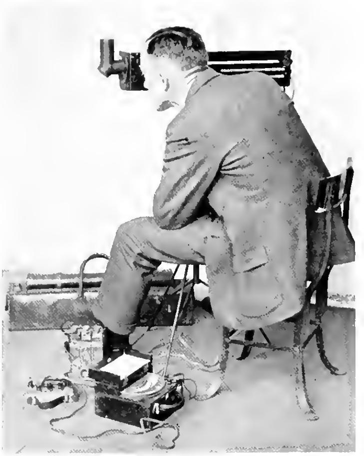


Fig. 17. Reading Illumination on a Horizontal Plane with the Sharp-Millar Photometer

Fig. 18. The Macbeth Photometer as Employed to Measure Illumination in the Horizontal Plane

level, with some readings on the vertical surfaces of the shelves (Fig. 20). In an art gallery, the vertical illumination on the picture walls is the feature it is desirable to study. In the show window some special points, such as the floor and the angle at which the

Fig. 19. Determination of the Illumination on a Desk Surface with the Foot-candle Meter

trim is ordinarily placed, should be studied; in the street or railway car, readings should be taken at the position of a newspaper held in the hand of the passenger at approximately 45 deg. from the horizontal. On the theatrical stage, it may be desirable to know the illumination on the scenery and on a number of vertical planes, for this is more important than horizontal measurements, since the audience views in general objects in this plane. In street lighting it is desirable to know the illumination on the surface of the street, on irregularities or obstructions in the street, and in some cases on the building fronts, while in the swimming pool the surface of the water is of interest.

Having obtained the average illumination on the horizontal plane under ordinary conditions, the product of this and the total floor area of the place gives the total effective lumens. The generated lumens of the lamp are known and the ratio of these two items gives the coefficient of utilization. This factor is of importance in designing an installation.

Brightness Measurement

As the elements upon which satisfactory illumination depends are being more carefully studied and generally understood, considerably more attention is being paid to the question of intrinsic brilliancy or surface brightness. This refers to the appearance of a light reflecting surface, or a light source when viewed from a particular direction. The question of comfortable and satisfactory illumination depends to a great degree on the proper co-ordination of relative brightnesses of objects in the field of view. This is usually specified in terms of candle-power per unit area; for brightness of a high order, it is stated in candle-power per square inch or per square centimeter; while for reflecting surfaces of a lower order or brightness candle-power per square foot or per square meter is applied. The term "Lambert" is sometimes used to express brightness and represents one lumen per sq. cm. radiated or reflected. One candle per sq. in. equals 0.4868 lamberts.

The brightness "apparent foot-candles" emitted from a source or surface, if distributing light uniformly in all directions, as from a hemispherical source or from a perfectly matt surface, when divided by π (3.14) gives candle-power per square foot.

While foot-candles as ordinarily used refers to the flux density received on a plane,

Fig. 20. Measuring Vertical Illumination of Wall Brightness with the Macbeth Photometer

apparent foot-candles may be used to conveniently express brightness with the understanding that "one foot-candle of brightness would be identical in appearance to (a) that produced by an illumination of one foot-candle upon a perfectly matt diffusing and reflecting surface of 100 per cent reflecting power, or (b) that of a surface source of light emitting at a density of one lumen per square foot, such flux being emitted in accordance with the cosine law."

Apparent foot-candles becomes at once a convenient term differing actually from the foot-candle values incident on a plane, or surface, by the absorption of that surface. A surface with five foot-candles incident would have an absorption of 20 per cent if the emitted light or brightness in a given direction was four apparent foot-candles.

Brightness measurements in apparent foot-candles are made with a portable photometer in a manner similar to illumination measurements. With photometers such as the Macbeth, employing the detached test plate, the aperture should be pointed at the surface to be measured and a reading taken of apparent foot-candles. The co-efficient of reflection of the test plate with which the photometer has been standardized is already known and given with the calibration of the photometer. Multiplying the reading of apparent foot-candles by this coefficient of reflection of the test plate gives this brightness value. To reduce the readings to values in units of candle-power per square foot, they should be divided by 3.1416; candle-power per square inch divided by 452 (3.1416 × 144); per square centimeter by 2920 (3.1416×929); per square meter divided by 0.292 (3.1416×.0929).

For portable photometers using the translucent cap at the end of the elbow rather than the detached test plate, such as the Sharp-Millar, the cap is removed and the elbow (with the mirror in its normal position) pointed at the surface to be measured and readings taken. These readings multiplied by the coefficient given in the standardization sheet accompanying the photometer give the candle-power per square inch of the surface observed. This coefficient takes into consideration the absorption of the translucent plate and the area values mentioned above.

Measurement of Reflection Factor

The portable photometer can also be used with satisfaction for determining the reflection factors of surfaces. The method of standardizing the photometer for this purpose and making the actual measurement is described in detail in the article, "Effect of Color of Walls and Ceilings on Resultant Illumination,"* and need not be discussed here.

Fig. 21. Reading Illumination on a Vertical Surface with the Foot-candle Meter

Illumination Test on a Single Unit

Frequently, in cases of competing equipment, illumination tests are conducted on an individual unit. The uninitiated often takes a single reading with a portable photometer directly beneath the unit. A little analysis will show that such a procedure will give very erroneous results. The unit may have a very poor efficiency and low illuminating power, and yet give a concentrated distribution of light, producing a very high reading directly under it. Another unit giving a broader distribution of light and being much more suitable for general illumination will give a low reading beneath the unit and yet a much higher output. The further we go from under the unit, the greater the area over which a given illumination is spread and the foot-candles at these distant points represent considerably more effective lumens.

For a fair comparison it is therefore necessary to take a series of readings radially from under the lamp and give these readings the proper weight as indicated in Fig. 22. For example, readings are taken four feet apart.

* General Electric Review, March, 1920.

The reading at station "A" may be considered the average over a circle two feet in radius; reading at station "B" the average over a ring whose outer radius is 6 ft., and whose inner radius is 2 ft.; reading at station "C," the average illumination over a ring whose outer radius is 10 ft. and whose inner radius is 6 ft. and so on. For readings on four-foot centers, the following calculation applies:

Reading at
$$\text{"A"} \times \pi\,(2)^2 \text{ sq. ft.} = \text{Lumens.}$$
Reading at
$$\text{"B"} \times \pi\,[(6)^2-(2)^2] \text{ sq. ft.} = \text{Lumens.}$$
Reading at
$$\text{"C"} \times \pi\,[(10)^2-(6)^2] \text{ sq. ft.} = \text{Lumens.}$$
Reading at
$$\text{"D"} \times \pi\,[(14)^2-(10)^2 \text{ sq. ft.} = \text{Lumens.}$$

A summation of these individual ring lumen values will approximate the total effective lumens produced by the unit provided the readings are carried out to a point where the foot-candles become negligible.

Rough Distribution Determination with Portable Photometer

It is often necessary to determine the characteristics of a lighting unit as to distribution when no regular photometer is available. An approximate idea can be obtained by using the portable photometer and calculating candle-power from the readings obtained. The unit under consideration should be set up in such a position that surrounding walls or ceiling do not reflect any appreciable amount of light and thus make the readings inconsistent. The center of the lamp should be placed at a definite distance above the photometric screen. The first reading, to obtain the downward light, should be taken with the plate of the photometer level directly beneath the unit. The second reading should be taken at a certain distance, say five feet, from beneath the unit with the plate of the photometer pointing directly at the unit. A similar reading taken ten feet from beneath the unit will give the candle-power at another angle, and so on. Example:

Hanging height, 10 feet.

Reading (a) beneath unit candle-power = reading × 10^2.

Reading (b) 5 feet from beneath unit, angle $\tan^{-1} 5/10 = 27°$.

Candle-power = reading × $\sqrt{10^2+5^2}$

Reading (c) 10 feet beneath unit, angle $\tan^{-1} 10/10 = 45°$

Candle-power = Reading × $\sqrt{10^2+10^2}$.

If this type of work is done to any appreciable extent a sighting device should be attached to the elbow of the photometer. If the graduated scale of degrees is used and angles calculated in advance for the hanging height and distance for that particular test

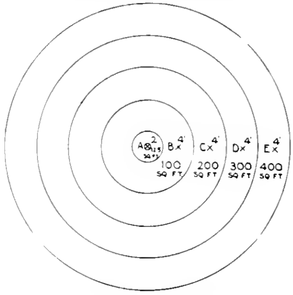


Fig. 22. Relative Ring Areas for Illumination Test on a Single Unit

station, precautions should be taken to insure that the instrument is set level. At best this method is inaccurate and is not recommended.

Street Illumination Tests

The greatest care is necessary in conducting illumination tests on the street. There are so many factors which may lead to erroneous conclusions that it is of the utmost importance to scrutinize such tests very closely before final conclusions are drawn. With the exception of the so-called white way lighting, the variation from maximum intensity to minimum intensity, while proportionally very high, is numerically only a fraction of a foot-candle. It will readily be seen that a slight error will nullify the value of the whole test.

Some of the causes of error are: Too few lamps are tested, causing too much weight to be given to the performance of an individual lamp. The lamp may not be in the proper position in the units which are being tested. This is particularly true where a refractor is used. In this case changing the position of the lamp would change the distribution curve, causing the maximum candle-power to come in an entirely different position than was intended, and changing the readings on the street. The current flowing through the lamps may also be high or low, due to the temporary fluctuations which are well known on any external circuit. For this reason the central station should notify the man at the switchboard to note current conditions during the time of the tests so that proper corrections can be made for any variations.

Persons inexperienced in photometry very frequently try to run street lighting tests and the personal error in reading, coupled with the inherent error in a portable photometer, may cause wide variation from the true reading. In comparing the performance of several units due consideration must be given to the reflection from buildings, shadows from trees, and condition of the road surface. Important decisions should not be rendered on street tests run with a portable photometer, but should be based on laboratory tests where exact conditions may be noted.

It is often necessary to run commerical street lighting tests and a great deal of valuable information may be secured if proper notations are observed. When such tests are to be run select a number of typical places around the city, measure off a line of stations between units along the center line of the road, another line of stations along the curb line. It is customary to make these stations about five feet apart, starting directly opposite one unit and going to a point directly opposite the next unit. If the units are not symmetrically spaced, an average spacing should be selected.

The method most frequently used in making these tests is to lay a calibrated target on the street at each of the stations mentioned above and read horizontal illumination direct. If a regular photometer target or external test plate is not available, a piece of clean white blotting paper may readily be calibrated and will give satisfactory service. The target must be large enough to cover the field of the photometer when viewed through the telescope, and it must be kept clean, free from unnatural shadows, and in a horizontal position during the test.

The target is calibrated in the same manner as is an external test plate of the photometer. The method is described under calibration of the Macbeth illuminometer.

When using the Sharp-Millar photometer for these tests remove the translucent test plate at the end of the horn and use the mirror in the elbow to reflect the light from the target to the photometer head. When using the Macbeth illuminometer the regular external test plate is used and the photometer pointed at it in the usual manner.

In order that the various tests may readily be compared and studied the values are usually plotted on rectangular co-ordinate paper and the location of the units marked on the sheet so that their relation to the curve may readily be noted.

Projector Tests

Projectors are divided into two general groups, those using a parabolic reflector or a modification, and those using a lens system. Under the first group come headlights for the various uses, flood-lights and searchlights; under the second group, theatrical spot lamps, stereopticons and motion picture projectors.

A portable photometer is used almost universally in testing, and reliable results may be obtained if it is properly calibrated and used. A sufficient number of readings must be taken to get average performance.

In the case of a parabolic reflector the unit should be turned on its horizontal axis and readings taken across the center of the beam at various positions and the results averaged. It is seldom possible to check a line of readings even though they are apparently taken at the same station. This is due to overlapping images of the filament which may cause a considerable difference in intensity at points only a few inches apart. Such variations are readily discernible by looking for the mottled appearance of the beam when thrown on a blank surface.

The beam of light reflected from a parabolic mirror has several peculiar features, the most important being the great distance to the point where it reaches its final distribution. The light from the center of the mirror has the widest distribution and forms the edge of the beam, while the light striking the edge of the mirror tends to fill in the center of the beam. Theoretically this crossing of the rays from the center and from the edge of the mirror never ceases, but practically the beam has reached its final form at from fifty to four hundred times the diameter of the mirror, depending on the relative size of the light source.

For this reason it is important when making tests to locate the photometer stations a considerable distance from the mirror. For automobile headlights 50 ft. has been found to be a satisfactory distance, and for larger headlights and floodlights about 150 ft., while for large searchlights the range should be from 1000 to 2000 ft.

When making a test on a projector with a parabolic mirror, focus the beam very carefully on a plane surface at about the distance of the photometer stations. After focusing, direct the center of the beam on the test plate of the photometer and take readings across the entire beam. If the beam has a spread of 10 deg. or more, the readings should be taken 1 deg. apart. If the beam is more concentrated, the readings should be taken closer together. A minimum of ten readings should be taken across the center of the beam in both a horizontal and vertical position. If a thorough study is to be made of the beam a considerable number of traverse readings should be taken, the number depending on the unevenness of the beam. As the curves of all the traverses must be averaged to get the final curve it is of prime importance that the line of stations at each traverse go through the center of the beam. The foot-candle readings taken at each station with the photometer are multiplied by the square of the distance from the projector to the photometer to get the beam candle-power. The candle-power of equi-distant points on each side of the center are averaged and the half of the average curve thus obtained is plotted on rectangular co-ordinate paper as shown in Fig. 23, which is a typical curve from a parabolic projector. The lumens in the beam are calculated by multiplying the beam candle-power at each degree on the curve by the following flux constants as described before.

This gives the lumens in each zone, and adding them gives the total lumens in the beam. The term "beam lumens" is sometimes used and designates the lumens in the beam to the point on the curve where the beam candle-power is 1/10 the maximum.

Candle-power at	ZONE From	ZONE To	Lumens Constant
0° 30'	0°	1°	.00096
1° 30'	1°	2°	.00287
2° 30'	2°	3°	.00478
3° 30'	3°	4°	.00669
4° 30'	4°	5°	.00860
5° 30'	5°	6°	.01051
6° 30'	6°	7°	.01241
7° 30'	7°	8°	.01431
8° 30'	8°	9°	.01621
9° 30'	9°	10°	.01810
12° 30'	10°	15°	.1186
17° 30'	15°	20°	.1648
22° 30'	20°	25°	.2098
27° 30'	25°	30°	.2531
32° 30'	30°	35°	.2945
37° 30'	35°	40°	.3337
42° 30'	40°	45°	.3703

* [illegible] hemisphere and its use is given [illegible] Society Transactions for August [illegible] 1920 by F. A. Benford.

A more accurate method of testing is to direct the beam into an integrating hemisphere, measure the lumens in each zone, and from this calculate the beam intensity at the various points. Average results are obtained by this method regardless of how mottled the beam appears.*

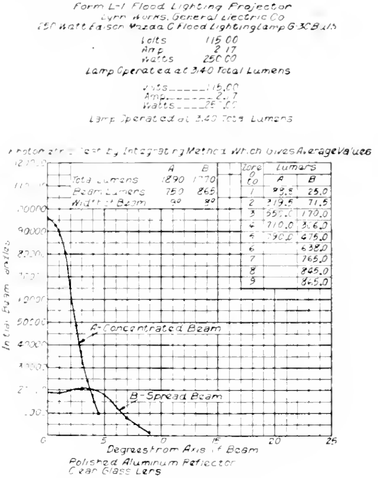


Fig. 23. Curve Showing Distribution and Essential Data Obtained from a Test on a Projector Unit

Measuring the illumination from a stereopticon or motion picture projector is a somewhat different problem. In this case the information desired is the intensity and uniformity of the illumination on a screen at a fixed distance and over a fixed area. Focus the lamp and objective lens carefully so as to get the most uniform screen. Divide the screen into 16 equal rectangles and take readings at the center of each rectangle. These are average readings for each section and give comparative figures of the uniformity of the illumination. The total lumens are secured by averaging the 16 readings and multiplying by the area of the screen in square feet. The results are shown on a sketch of the screen, divided into 16 sections with the readings placed in each section.

When taking photometer readings it is always desirable to take from three to five readings at each station and average the results for the final reading. This will materially reduce errors from faulty settings and voltage variations.

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Methods for the Production and Measurement of High Vacua

PART VI

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This installment contains a discussion of the absorption of gases by charcoal and palladium black and their use at very low temperatures for improving the vacuum in sealed off tubes. The next installment will deal with other physical chemical methods of producing high vacua.—Editor.

While the use of vacuum pumps is undoubtedly the most generally applicable method of obtaining very low pressures, there are other methods of a physical chemical nature which are of great utility and importance in high vacuum technique. Charcoal, palladium black, and similar substance have been found to absorb large volumes of gas when exposed to very low temperatures. The high reactivity of alkali and alkaline earth metals with all gases except argon, helium (and the other elements of the inert group) has been utilized by different investigators for "cleaning up" residual gases. The fact that the electrical discharge in a low pressure tube causes a gradual disappearance of the gas has been known for a long time and explains the progressive "hardening" of the gas-filled X-ray tubes. In the incandescent lamp industry various chemicals or "getters" are also used for the purpose of improving the vacuum in the lamp after it is sealed off from the pump. All these are illustrations of physical chemical methods of producing high vacua, which we shall discuss in the succeeding section.

I ABSORPTION OF GASES BY CHARCOAL[1]

Dewar's Investigations on the Use of Charcoal in the Production of High Vacua

That charcoal and other substances in a finely divided state have the power of taking up large volumes of different gases was observed even in the 18th century. Sir James Dewar[2] was the first investigator to make use of this phenomenon for the production of high vacua. He observed that charcoal made from coconuts has very much higher absorptive power than that from other sources. He also found that by heating the charcoal in vacuo for a long time, to expel gases already absorbed and then cooling it to a low temperature, large volumes of the ordinary gases could be readily "cleaned-up," so that the pressure in a sealed-off bulb was diminished to a very low value. Thus, in the case of a 2000 cm.^{3} bulb containing air at 2.19 mm. pressure, 20 grammes of charcoal cooled in liquid air (−185 deg. C.) affected a reduction in the pressure to 0.00025 mm. The absorptive power for different gases was observed, in general, to increase with the boiling point of the gas. Some of the earlier observations are shown in Table XIV, although it must be noted that much larger absorptions have since been obtained owing to improved technique in the preparation of the charcoal. The volumes absorbed are given in cm.^{3} at 0 deg. C. and 760 mm. pressures.

TABLE XIV

GAS ABSORPTION BY CHARCOAL (per cm^3)

	Boiling Point Deg. Cent.	Volume Absorbed at 0° C.	Volume Absorbed at −185° C.
Helium	−268.6	2 cm^3	15 cm^3
Hydrogen	−252.9	4	135
Argon	−186.2	12	175
Nitrogen	−195.8	15	155
Oxygen	−183.0	18	230

The effect of temperature on the relative absorption of helium and hydrogen is shown by Table XV. "It will be observed that the absorption of helium, small in comparison to that of other gases, even hydrogen, increased therefore enormously at the lowest temperature," which is below the boiling point of liquid hydrogen.

Further experiments on the use of charcoal for the production of high vacua were carried out by Blythswood and Allen.[3] Their results are extremely interesting. They

[1] The literature on this subject is so immense that it is impossible to do more than refer briefly to the most important results. For further references the reader may consult the following:
W. Ostwald, Lehrb. d. allgem. Chem., I, Aufl. 1, p. 778 (Reference to literature previous to 1890).
H. Freundlich, Kapillarchemie (1909) pp. 91–125.

[2] Proc. Roy. Soc. ... 122 and 127 (1904); Encycl. Britann. ... 751 (1912); Engineering (London), June 15, 1906, June 14, 1917. His first investigations were reported in ... Feb. 15, 1875.

[3] Phil. Mag. ... 497 (1905).

observed that by using charcoal at the temperature of liquid air, very large volumes of air could be absorbed. The rate of absorption was found to be given accurately by the first order reaction equation.

$$\frac{dx}{dt} = k\ (A - x)$$

where

x = amount absorbed at time t

A = total amount absorbed when equilibrium is attained,

and

k = constant.

In one experiment, using 216 gms. charcoal, a volume of about 925 cm.^{3} was exhausted from an initial pressure of 40 mm. to 0.0009 mm. of mercury in about 3 hours.

Absorption, Adsorption, Occlusion, and Sorption

The clean-up of gases by charcoal and similar substances is apparently a complex phenomenon. It is certainly not a case of chemical reaction in the same sense as the clean-up of oxygen by a heated tungsten filament (where WO_3 is formed as a result of the reaction), although there is some question as to whether in the case of oxygen taken up by charcoal there is a chemical action. Also we are familiar with the occlusion of gases by metals. Here we are apparently dealing with true cases of solution, obeying laws similar to the solutions of nitrogen or oxygen in water. While there is some evidence of similar phenomena in the specific case of charcoal and hydrogen (see below) a theory of solution will not account for the general phenomena of clean-up of gases by charcoal. On the other hand, we find that all clean surfaces, after evacuation, absorb definite amounts of different gases. This seems to be a case of condensation on the surface, of a layer of gas about one atom in thickness. The gas molecules are attached to the surface by quasi-chemical forces. Increase in temperature causes rapid evaporation, while decrease in temperature leads to equally rapid condensation of gas on the surface. To distinguish these different kinds of physical chemical reactions, certain terms have been introduced into the literature on the subject.

TABLE XV

RELATIVE ABSORPTION OF HYDROGEN AND HELIUM AT LOW TEMPERATURES

Temp. Deg. Cent.	Helium	Hydrogen
—185	2.5	137
—210	5.	180
—252	160	250
—258	195	

J. W. McBain[4] has suggested the term "sorption" as a "generic and non-hypothetical term for phenomena which frequently occur together," to include all cases of clean-up of gases by metals, charcoal, or other substances.

The surface condensation of gases is usually referred to as *adsorption*, while the solution of gases in metals or liquids is regarded as an *absorption* phenomenon. The term "occlusion" is also used frequently in referring to the gases present in metals. No doubt, a large number of cases of occlusion of gases by metals ought to be classified as true absorption (solution) phenomena; while other cases must be regarded as illustrations of adsorption reactions. Under these conditions the use of the term occlusion seems superfluous. While the theories of sorption phenomena are discussed in a subsequent section, it has been considered best to introduce these terms in the present connection because of their value in the classification of the different cases of clean-up.

Adsorption of Gases by Charcoal. General Investigations

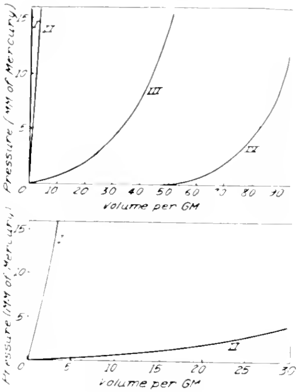
The clean-up of gases by charcoal is to a great extent an adsorption phenomenon, the condensation of the gas occurring on the large surface presented by the pores in the charcoal. The adsorptive power varies widely with the method of preparation and structure, so that it is impossible to draw any conclusions by comparing the results obtained by different investigators. On the other hand, it has been possible to obtain interesting results by studying the behavior of any given specimen of charcoal, and from these results have been derived certain general conclusions regarding the "laws" of adsorption phenomena.

The relation between the amount of gas adsorbed at constant temperature and the residual pressure is of great importance. The measurements are carried out as follows: The charcoal (or other solid adsorbent) in a tube is heated to a high temperature (400 deg.-600 deg. C.) and simultaneously evacuated from previously adsorbed gases. A measured volume of gas is then brought in contact with this material and the pressure of the residual gas measured after equilibrium is attained.

[4] Phil. Mag. (6), *18*, 916 (1909).
Zeits. physikal. Chem. *68*, 471 (1909).

This operation is repeated until, finally, the adsorbent becomes saturated.[1]

Most of the investigators in this field have measured the adsorption at pressures above 1 mm. of mercury, and there are very few published data on the adsorptive power of



Figs. 53 and 54

charcoal at the low pressures which are of interest in vacuum technique.

H. Baerwald[6] showed that by heating charcoal to over 500 deg. C., its absorptive power is increased considerably; also that charcoal from coconut shell is a much better absorbent than that from the soft part of the nut, or from wood.

The absorption of nitrogen, oxygen, and air by coc nut shell charcoal at about 18 deg. C. has been measured by F. Bergter.[7]

The measurements at low pressures (1-10 mm mercury) show that at the same pressure oxygen is absorbed in about 30 or 40 times as great an amount as nitrogen, while the absorbing power for air is about 3 times that of nitrogen. At low pressures the amount absorbed is proportional to the final pressure. It was also observed that in the case of nitrogen, about 90 per cent of the total amount is absorbed almost instantaneously, while the rest is absorbed very slowly.

In the following tables and curves of results obtained by different investigators, the pressure is given in mm. of mercury, the volume adsorbed, in cm.[3] (measured at 0 deg. C. and 760 mm.) per 1 gm. charcoal (except where otherwise mentioned), and the temperatures are given in degrees on the absolute or Kelvin scale. (T = deg. Centig. + 273).

G. Claude[8] has measured the absorption of H_2, He, Ne, and N_2 by charcoal at very low temperatures and low pressures. Table XVI gives the results obtained, which are shown graphically in Figs. 53 and 54.

The adsorption of helium was observed to be extremely small, 0.21 cm.[3] being adsorbed at a pressure of 27 mm.

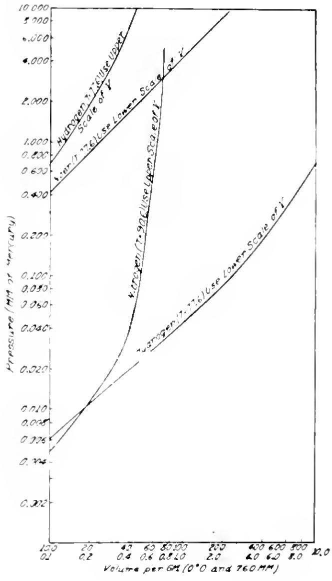


Fig. 55

It will be observed that although hydrogen has a lower boiling point than that of neon, the adsorptive power of charcoal for the latter is much lower than that for hydrogen. At very low pressures the amount adsorbed tends to become proportional to the pressure. For higher pressures, the form of the adsorp-

[1] [illegible] of the apparatus used and method of measurement are [illegible]
[illegible] Dewar [illegible] 751 (1912) Fig. 5.
[illegible] W. [illegible] R. [illegible] S. [illegible] 28, 9 (1907).
[illegible] H. [illegible] Zeit. phys. Chem. [illegible] 129 (1910).
[illegible] Zeit. phys. Chem. [illegible] 641 (1910).
[illegible] B. [illegible] Zeit. phys. Chem. 86, 204 (1913).
[illegible] 27, 84 (1907).
[illegible] 872 (1912). The paper [illegible] gives a large [illegible] work.
[illegible]

TABLE XVI

ADSORPTION OF GASES BY CHARCOAL (Claude)

NITROGEN (T = 90.6)		HYDROGEN (T = 77.6)		NEON (T = 77.6)	
P	V	P	V	P	V
0.004	9.35	0.006	0.105	0.45	0.105
0.010	18.70	0.0115	0.21	0.88	0.21
0.032	37.4	0.0205	0.42	1.30	0.32
0.088	46.6	0.036	0.84	1.74	0.42
0.385	56.0	0.083	2.05	3.50	0.84
1.107	65.3	0.176	3.71	5.30	1.22
11.50	93.0	0.475	8.40	7.20	1.63
33.2	103.	1.060	14.	11.30	2.44
90.	112.	3.50	28.	15.5	3.25
247.	121.	8.7	42.	19.4	4.06
		20.6	56.	30.5	6.18
		43.7	63.	40.5	8.01

TABLE XVII

ADSORPTION OF GASES BY CHARCOAL (Titoff)

HYDROGEN			NITROGEN			CARBON DIOXIDE		
P	V	1/n	P	V	1/n	P	V	1/n
			(I) T = 353					
10	0.0064		11.4	0.0452		4.3	0.2800	
35.3	0.0217	0.97	26.6	0.1154	1.11	12.5	0.759	0.93
73.9	0.0446	0.98	91.8	0.4330	1.07	26.6	1.539	0.94
183.1	0.1097	0.99	198.9	0.9021	0.95	54.4	2.985	0.93
310.8	0.1778	0.91	297.2	1.3170	0.94	120.9	5.840	0.84
454.0	0.2538	1.00	470.9	2.007	0.92	230.4	9.541	0.76
611.5	0.3413	1.00	622.7	2.572	0.89	356.4	13.07	0.72
727.3	0.4011	0.93	770.1	3.180	1.00	520.3	17.06	0.70
			(II) T = 273					
17.4	0.0384		4.3	0.111		0.5	0.849	
39.3	0.0983	1.16	12.1	0.298	0.95	3.2	3.460	0.68
66.9	0.1490	0.78	39.3	0.987	1.02	10.9	8.506	0.73
119.4	0.2704	1.03	129.8	3.043	0.94	25.4	15.15	0.68
206.9	0.4514	0.93	229.4	5.082	0.90	83.0	27.78	0.43
427.5	0.9139	0.97	340.1	6.047	0.83	173.5	39.90	0.49
642.1	1.3430	0.94	562.3	10.310	0.76	315.9	50.24	0.39
			(III) T = 194					
7.9	0.059		1.5	0.145				
19.0	0.148	1.06	4.6	0.894				
67.5	0.531	1.01	12.5	3.47				
141.9	1.121	1.01	66.4	12.04	0.75			
236.9	1.892	1.02	149.5	20.03	0.63			
347.9	2.787	1.01	271.4	27.94	0.56			
471.8	3.607	0.85	388.4	33.43	0.50			
561.9	4.276	0.97	542.9	38.39	0.41			
721.6	5.414	0.94	740.6	43.51	0.40			

tion relation which has been used, as a general rule, is,

$$v = k \cdot p^{1/n} \qquad (31a)$$

where

v = volume of gas (measured under definite conditions) per unit weight of adsorbent.

p = pressure.

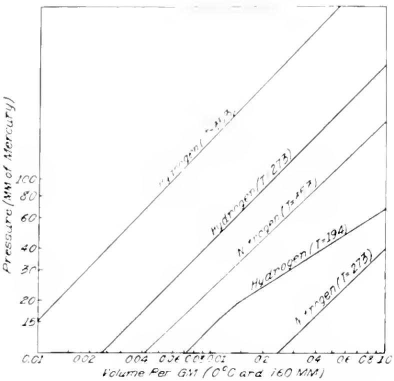


Fig. 56

In this equation k and n are constants which depend on the nature of both the adsorbent and gas. Since this relation can be expressed in the form,

$$\log v = 1/n \log p + \log k \qquad (31b)$$

it is evident that if p and v are plotted on logarithmic paper, a straight line should be obtained whose slope gives the value of 1/n. Fig. 55 shows Claude's data plotted in this manner. In this case, the value of 1/n is approximately unity, corresponding to a linear relation between p and v. At higher pressures and concentrations, the values of 1/n tend to decrease more and more. This is illustrated by Titoff's results[9] (see Table XVII and Fig. 56) on the adsorption of various gases by coconut charcoal.

The effect of increased temperature in decreasing the adsorptive power is quite evident. The relative adsorption of different gases at the same pressure and different temperature is shown by the following data (Table XVIII) given by Titoff.

Miss Ida F. Homfray published in 1910[10] the results of quite an elaborate series of measurements on the adsorption by coconut shell charcoal of argon, nitrogen, carbon monoxide, carbon dioxide, methane and ethylene.

The observations with the first four gases are shown graphically in the curves given in Figs. 57 to 60. The temperatures are given in degrees absolute, and the volumes absorbed are referred to the constant weight, 2.964 gm., which was used in all the experiments.

The results for helium are of interest.[11] At the temperature of liquid air, the following absorption data were obtained:

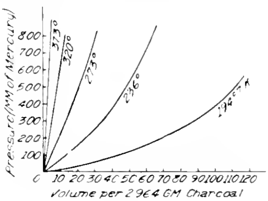


Fig. 57

P (mm. of Mercury)	V (Per gm. of Charcoal)
120.	0.337
171.	0.465
235.	0.81
427.6	1.17
705.0	1.84

[9] Loc. cit.

[10] Zeits physikal. Chem., ..., 129 (1910).

[11] The adsorption of helium by charcoal has also been measured recently by S. McLean, Trans. Roy. Soc. Can. 12, III, 79 (1918); Chem. Abst. 13, 1667 (1919). The amounts of helium adsorbed by charcoal at the temperature of liquid air were observed to be very small.

TABLE XVIII

COMPARATIVE ADSORPTION OF DIFFERENT GASES (Titoff)

At p = 100 mm.

[illegible]	−79	−23.5	0	30	80	151.5
[illegible]	0.79		0.227		0.0[illegible]07	
[illegible]	15.8[illegible]		2.344	1.178	0.4688	0.1633
[illegible]	97.27*		30.41	15.89	4.920	1.062
[illegible]		112.2	69.02	20.24	7.96	2.77

[illegible] CO_2 solidifies at −79.

The sorption of hydrogen by charcoal at temperature of liquid air has been specially investigated by J. B. Firth,[12] and J. W. McBain.[13] Both investigators have observed that equilibrium is attained in this case only after a lapse of many hours. Most of the gas is apparently condensed instantaneously on the surface (true adsorption). This is followed by a gradual diffusion of the hydrogen into the charcoal the rate of which obeys Fick's law of diffusion, as shown by McBain, and which must be regarded as due to solution or occlusion of the gas in the charcoal. Firth finds that at equilibrium the relation between pressure and volume of gas absorbed per unit weight of charcoal is not given by a linear relation, but by an equation of the form.

$$v = k.p^{1/4}$$

Table XIX gives the equilibrium data observed. The pressures are given in mm. of mercury, and V gives the volume absorbed (corrected to 0 deg. C., 760 mm.) per gm. charcoal.

McBain on the other hand obtains the relation

$$v = k\ p^{1/2}$$

which would point to the hydrogen being absorbed in the atomic condition. At a pressure of 19 mm. and the temperature of liquid air the amount of hydrogen taken up per gm. of charcoal is 4 cm ^{3} (at 0 deg. C. and 760 mm.) which is much less than that observed by Firth.

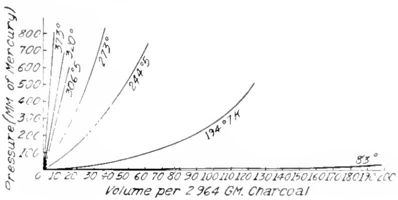


Fig. 58

TABLE XIX

ABSORPTION OF HYDROGEN BY CHARCOAL AT THE TEMPERATURE OF LIQUID AIR (Firth)

P	V	P	V
9	21.5	90	59.3
17	32.1	126	63.1
30	46.5	186	69.2
51	53.3	245	76.0
59	56.0		

[12] Zeits. physical Chem., *86*, 294 (1913).
[13] Loc. cit.

Use of Charcoal at Low Temperatures in High Vacuum Investigation

The only comprehensive data in the literature on adsorption at very low temperatures and low pressures is that published by Claude, which was mentioned above. From his data it is possible, assuming the linear relation to

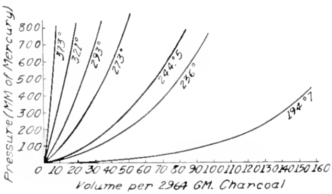


Fig. 59

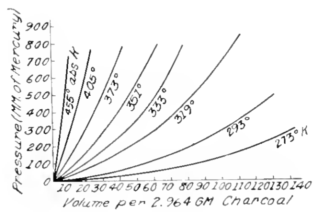


Fig. 60

be valid down to very low pressures, to calculate the amounts of nitrogen and hydrogen that can be occluded by charcoal at equilibrium pressures below 1 bar. Table XX gives these amounts in terms of the volume measured at *1 bar pressure* (and 0 deg. C.)

TABLE XX

ADSORPTION OF CHARCOAL AT LOW TEMPERATURES

(Extrapolated from Claude's data)

Hydrogen (T = 77.6)		Nitrogen (T = 90.6)	
P (bars	V	P (bars)	V
8.	106,000	5.3	9,500,000
1.	13,250	1	1,800,000
0.1	1,325	0.1	180,000
0.01	133	0.01	18,000
0.001	13	0.001	1,800

That is, at a pressure of 0.01 bar (which is a maximum pressure for the efficient operation of hot cathode high vacuum devices), 1 gram of charcoal (such as used by Claude) would clean up about 130 cm.^{3} of hydrogen or 18,000 cm.^{3} of nitrogen, from a pressure of 1 bar down to 0.01 bar.

Woodrow[14] measured, with a Kundsen gauge, the amount of clean-up of different gases by charcoal at liquid air temperatures. Neither the volume of the apparatus nor weight of charcoal are given. The latter was heated under simultaneous evacuation till the pressure fell to 1.5×10^{-6} mm. of mercury (2×10^{-3} bar) and hydrogen, oxygen, or nitrogen was then introduced at an initial pressure of about 0.65 bar. The rate of clean-up in each case as followed with the gauge is shown in the table:

PRESSURE IN BARS

Time	Hydrogen	Oxygen	Nitrogen
0	0.647	0.667	0.600
5 sec.		0.387	
10 sec.		0.227	
1 min.	0.613	0.0027	0.020
5 min.	0.547	0.002	
20 min.	0.387		
1 hr.	0.253		0.007
3 hrs.	0.180	0.002	
10 hrs.	0.180	0.002	0.007

Miss M. Daly and the writer have carried out some experiments in this laboratory on the adsorption of gases by charcoal at low temperatures. Specially activated products (see below), supplied us by the kindness of Dr. F. M. Dorsey, were used in this work. Pressures were determined by means of the ionization gauge, and the rate of clean-up observed of both hydrogen and residual gases present after sealing off the pump. In the latter case the gauge and tube containing 5 gm. charcoal with a large bulb (total volume =3000 cm.^{3}) were well exhausted on the condensation pump, heating the charcoal for over an hour to 360 deg. C. After sealing this system off the pump, the pressure was measured, and then liquid air put on the charcoal. The pressures before cooling the latter, and after, were:

V	Initial Pressure Bars	Final Pressure
5,000 cm	0.022	0.0004
3000 cm	0.036	0.0004
3000 cm	0.92	0.0006

It may be noted that the sensitivity of the galvanometer used with the ionization gauge was such that 0.0004 bar was about the lowest pressure that could actually be measured.

In carrying out experiments with hydrogen, the same apparatus was used, except that another side tube was sealed on in which was contained a small thin-walled glass pellet (volume of 3 cm.^{3}) filled with hydrogen at a known pressure. After exhausting the gauge, charcoal tube, and bulb, this system was sealed off, the hydrogen pellet broken by shaking, and the residual pressure observed after immersing the charcoal tube in liquid air. Five gms. of activated charcoal was used as in the previous experiments. The residual gas pressure was also measured before breaking the pellet. Table XXI shows some of the results obtained.

In general it required about an hour to attain equilibrium. In accord with McBain's observations (mentioned above) it was found that the initial condensation was followed by a slow diffusion of gas into the charcoal.

A certain fraction of this clean-up was no doubt due to the action of the gauge itself. As will be shown in a subsequent connection, there is an electrical clean-up which occurs in all hot-cathode devices. Furthermore, in presence of a heated filament atomic hydrogen is formed which is cleaned up at the temperature of liquid air. A blank experiment carried out without the use of charcoal gave

$V = 340$; pressure after seal off = 1.60 bar.

On breaking the hydrogen pellet, the pressure rose to 7 bars then fell, owing to clean-up by gauge, to 2 bars. Liquid air was put on the side tube and the pressure fell in the course of 6 hours to 0.16 bar. On removing the liquid air, the pressure came back to 1.2 bar.

In the measurements with charcoal the gauge filaments were lighted only during the time necessary to take a pressure reading, so that any error due to clean-up in the gauge was certainly not very large.

It is evident from these measurements that with a charcoal tube immersed in liquid air it is possible to absorb appreciable volumes of hydrogen and obtain residual gas pressures of less than 0.0001 bar.

Preparation of Charcoal. "Activated" Charcoal

The methods of preparing cocoanut charcoal as used by M. W. Travers,[15] J. W. McBain[16] and others is as follows: The soft part is heated in a muffle furnace for several hours at just below a red heat until no more vapor is evolved; then the temperature is

[illegible]

raised to a dull red heat for 30 seconds. After introducing the charcoal into a tube (and before use as an adsorbent) it is heated to 440 deg. C. (bath of boiling sulphur) for several hours, in vacuo.

As mentioned previously, and as is evident from a comparison of the results on adsorption obtained by different experimenters, the absorbing power of charcoal is influenced largely by its structure, that is, mainly the porosity. It was observed that charcoal from the shell of the coconut gave a much greater absorption per unit volume of charcoal than that obtained from less dense forms of wood. But a great stimulus to the investigation of the effect of structure of charcoal on its adsorbing power was provided during the recent war by the necessity of developing a highly efficient absorbent for gas masks.

As a result there was evolved a technique for the production of a specially active form of charcoal which will no doubt be of equal utility in the peaceful art of vacuum production.[17]

Lemon observed in 1915 that different samples of charcoal made from the same material (coconut shell) showed very wide variations in absorptive power. It was found that this was due to variations in heat treatment and that a considerable increase in absorptive power, "activation," could be produced by repeated evacuations at 650 deg. C., each evacuation being followed by an absorption of air at the temperature of liquid air. On the other hand, by treating the charcoal to between 800 deg. C. and 900 deg. C. during evacuation, a decrease in absorptive power (de-activation) resulted.

The theory was advanced that the successive absorptions of air oxidize non-volatile hydrocarbons present in the charcoal. As a result an air-process of activating charcoal was evolved which consisted essentially of the following operations:[18]

1. Initial distillation of cracked coconut hulls to a temperature of 850 deg. C. to 900 deg. C., and
2. "Air treating" this carbonized material, screened 6 to 14 mesh, at 350 deg. C. to 400 deg. C., for a certain length of time.

The essential characteristics of an active charcoal are:[19]

1. High and fine-grained porosity.
2. The presence of amorphous base carbon.
3. Freedom from adsorbed hydrocarbons.

TABLE XXI

CLEAN-UP OF HYDROGEN BY ACTIVATED CHARCOAL (M. Daly and S. Dushman)

V	Press. After Sealing Off	Initial Press. of Hydrogen	Final Press. at Room Temp.	Press. At Liquid Air Temp.
3025	0.0180 bar	0.31 bar	0.014	0.0004
100	0.104 bar	8.64 bar	0.02	0.0004
3025	0.022 bar	8.33 bar	2.0	0.15
106	0.28 bar	17.7 bar	0.24	0.0016

To secure these objects it is necessary to use dense woods, carry out the distillation at relatively low temperatures, and then oxidize the hydrocarbons without injuring the carbon base to any measurable extent. "The permissible range of temperatures for the latter operation is a relatively narrow one, only about 50 to 75 deg." For air oxidation this lies between 350 and 450 deg. C. Subsequently a steam process of activation was adopted, and for this reaction the optimium temperature is between 800 deg. and 1000 deg. C. Other methods of activation have been used in Europe. All these processes yield charcoal which is much more active than that obtained by the simple distillation process used at one time.

"From a study of the slope of the vapor pressure curves of liquids adsorbed upon such charcoal, the indications are that the pores have, if a cylindrical form be assumed, an average diameter of about 5×10^{-7} cm. On this basis, 1 cm.^{3} of active charcoal would contain about 1000 sq. meters of surface."

The density of activated charcoal from coconut shells is about 0.4. Hence 1 gm.

[17] The results of the investigations on this subject carried out by the Chemical Warfare Service, U. S. A., have been published mainly in the following papers:

A. B. Lamb, R. E. Wilson, and N. K. Chaney, Journ. Ind. and Eng. Chem. 11, 420, 1919, on "Gas Mask Absorbents."
F. M. Dorsey, ib. 11, 281, 1919, on the "Development of Activated Charcoal."
H. B. Lemon, Phys. Rev. *14*, 282, Oct. 1919.
The writer is indebted to these publications for the information on the properties and preparation of activated charcoal.

[18] F. M. Dorsey, loc. cit.

[19] A. B. Lamb, R. E. Wilson and N. K. Chaney, loc. cit.

would contain about 2500 sq. meters of surface. Assuming that the clean-up by charcoal is due to a condensation of gas molecules on the surface, and that the diameter of a hydrogen molecule is about 2×10^{-8} cm., it would require approximately 2,000 cm.^{3} (measured at 0 deg. C. and 760 mm.) to cover the surface of 1 gm. of charcoal. Compared with this the absorptions obtained by Miss Homfray, Titoff and Firth, even at atmospheric pressure are very low, which may be accounted for partly by the smaller porosity of the charcoal used by them.

As mentioned above, the results obtained by the use of active charcoal in high vacuum investigations carried out in this laboratory have been very encouraging. It is hoped that we will be able to publish the results of further experiments on this subject in the near future.[20]

(II) ABSORPTION OF HYDROGEN BY PALLADIUM BLACK

Absorption Relations

Palladium, on being heated, allows hydrogen to pass through it quite freely. This observation was utilized in early forms of gas-filled X-ray tubes to soften tubes which became hard because of electrical clean-up. Further investigation has shown that the phenomenon is due to the absorption of hydrogen which then diffuses through the metal into the tube.

This absorption of hydrogen by palladium has been studied by a number of investigations. Hoitsema[21] found that at temperatures above 100 deg. C., the absorption law is,

$$v=k\sqrt{p}$$

where v denotes the volume absorbed per unit weight and p is the pressure. This indicates that the hydrogen is occluded in the atomic condition. The absorption was measured at pressures ranging from 1 to 5000 mm. and at temperatures from 0 deg. to 250 deg. C. The results have therefore no bearing on the utility of palladium as an absorbent at low pressures and low temperatures. It may be stated that both metal foil and palladium black (described below) were used in this investigation.

A. Sieverts[22] has also investigated the behavior of hydrogen and palladium (wire, foil and "black"), with a view to evolving a satisfactory theory of the phenomenon. He considers that the absorption is a true case of solution. The range of pressures used was from 1 to 760 mm. and the solubility determinations were carried up to temperatures as high as 820 deg. C. The solubility was found to vary with the nature of the sample used. At higher pressures, the relation

$$v=k\sqrt{p}+k_2p$$

was found to be more in accord with the data. This relation was obtained for all the samples.

A. Holt, E. C. Edgar and J. B. Firth[23] have concluded that palladium can exist in the form of both active and inactive modifications, as far as absorption is concerned, and the activity of any sample decreases with time. By heating (in hydrogen) the absorbing power can be revived. Furthermore, palladium shows phenomena of diffusion similar to those observed by McBain in the case of hydrogen and charcoal.

S. Valentiner has carried out a series of measurements on the absorption of hydrogen at relatively low pressures.[24] The results obtained were not very satisfactory. At the same equilibrium pressure it was found possible to absorb amounts of gas which differed for different samples. Apparently the absorbing power varies not only with the degree of fineness of the palladium black but also with its subsequent heat treatment during evacuation. The writer has made the same observations on different samples of the material without being able to determine the cause of this. Some of the data obtained by Valentiner are tabulated in Table XXII. The remarkable increase in absorptive power at −190 deg. C. is quite evident, although the actual absorptions for the same equilibrium pressure vary widely. In the table, P gives the pressure in mm. of mercury, and V the volume at standard pressure and temperature per gm. of palladium black.

Compared with the absorption of hydrogen by charcoal (Claude's data, Table XVI), the absorption by palladium at liquid air temperature is observed to be much greater.

[20] Although not bearing directly on the topic of this discussion, it is of interest to observe that the selective absorption of different gases by charcoal may be used for the purification of gases. Thus, where it is desirable to obtain pure helium, charcoal in liquid air may be used to absorb impurities such as nitrogen, oxygen and even hydrogen. Similarly the latter gas may be freed of traces of nitrogen and oxygen. In this connection the following recent publications may be consulted:

1) H. B. Lemon and K. Blodgett. Studies of the Absorption of Gases by Charcoal. Phys. Rev. *15*, 394 (1920).
2) R. E. Wilson. Note on the Adsorption of Nitrogen and Oxygen by Charcoal. Phys. Rev. *16*, 8 (1920).
3) H. H. Sheldon. Charcoal Activation. Phys. Rev. *16*, 165 (1920).

[21] Zeit. phys. Chem. *17*, 1895.

[22] Zeit. [illegible] Chem. 88, 103 and 451 (1914). This paper [illegible] numerous references to previous literature.

[23] [illegible] Chem. 82, 513 (1913).

[24] [illegible] 1911.

Preparation of Palladium Black

The method of preparation has been described by Hoitsema.[25] With slight variation this method has been used by the writer as follows: The palladium in the form of sheet or wire is dissolved in aqua regia, evaporated on a water bath till acid vapors have disappeared; the solution is then diluted, warmed, and concentrated solution of sodium carbonate added to neutralize free acid. A slight amount of acetic acid is then added, the solution is warmed, and a warm concentrated solution of sodium formate added. The palladium comes down as a black flocculent precipitate which settles rapidly at the bottom of the beaker. The supernatant liquid is decanted, and the precipitate washed with distilled water till the wash water shows no traces of chlorides. The palladium "black" is then washed with alcohol and transferred to a U-tube, where it is dried by blowing air over it and then evacuated on a rough pump. The U-tube ought to have side tubes through which gas can be passed and constrictions at which it can be sealed off later. After the rough evacuation (with slight warming of the U-tube), hydrogen is passed over the palladium black for some time, and while the gas is still passing through the tube the latter is sealed off at the constrictions. This leaves the palladium black in equilibrium with hydrogen and it can be kept active for a long time.

For use in exhaust work, the U-tube is opened and a sample transferred to a tube such as is used in the case of charcoal. It is well to cover the top of the palladium black with glass wool in order to prevent it from being drawn into the rest of the apparatus when vacuum is applied.

[25] Loc. cit.

Experiments on the Use of Palladium Black in the Production of High Vacuua

A number of experiments have been carried out in this laboratory by Mr. A. G. Huntley, Miss M. Daly and the writer. While the behavior of palladium black was found to be extremely erratic, the results obtained showed that it is possible to obtain samples which possess very high absorbing power.

An ionization gauge with an appendix containing about 1 gm. of palladium black was well exhausted on a condensation pump and sealed off at a residual gas pressure of about 0.2 *bar* (the gas consisting probably of nitrogen and hydrogen). On immersing the appendix in liquid air, the pressure decreased to 0.004 bar with the gauge filament lighted. On turning off the filament for some time, and then lighting it for an instant, the pressure was observed to have decreased still further to 0.0005 bar. Apparently, there is a continual slight evolution of gas from the walls of the gauge and filament leads even after the metal parts have been bombarded for a long time. In other experiments pressures as low as 0.0001 bar were obtained in a sealed off gauge with a palladium tube immersed in liquid air.

A number of experiments were carried out using palladium black for absorbing the residual gases in a small kenotron exhausted on an oil pump only. An ordinary lamp exhaust system was used giving an exhaust pressure of about 1 bar. A few *milligrams* of palladium black were placed in a kenotron (about 100 cm.³ volume) which contained a 6-volt 2.5-ampere tungsten filament and a cylindrical molybdenum anode about 1/4 in. in diameter by 7/8 in. in length. The tube was exhausted on the oil pump, with simultaneous heating in an oven for 30 minutes at

TABLE XXII

ABSORPTION OF HYDROGEN BY PALLADIUM BLACK (Valentiner)

Temp. = 20° C		Temp. = 20° C		Temp. = −190° C	
P	V	P	V	P	V
0.001	0.10	0.014	0.27	0.0005	2.05
0.005	0.26	0.031	0.33	0.0015	2.11
0.037	0.40	0.056	0.37	0.001	3.06
0.110	0.52	0.087	0.41	0.001	9.1
0.190	0.59	0.184	0.49	0.002	33.0
0.315	0.70	0.30	0.55	0.005	40.
0.52	0.82	0.52	0.61	0.012	47.2
0.76	0.92	0.88	0.67	0.025	63.0

360 deg. C., and sealed off. The metal cylinder was then bombarded to a white heat by making the filament cathode. The gas evolved were absorbed rapidly by the palladium black, in spite of its being above room temperature, and finally the vacuum became so good that excellent space charge characteristics were obtained. Special experiments showed that in order to obtain this condition the pressure must be at least as low as 0.05 bar. Thus even with a few milligrams of palladium black at room temperature it was possible to clean up appreciable quantities of gas. Similar results were obtained time after time. In fact a large number of small kenotrons and pliotrons were exhausted in this manner with the regular exhaust system used in lamp factories, and without having to use a condensation pump or liquid air.

As subsequent investigation showed that the same results could be obtained with the very much cheaper activated charcoal, and furthermore, as some samples of palladium black absolutely failed for some undetermined reason to act as absorbent, this method was used for only a short time. The results, however, suggest interesting possibilities in the production of high vacua by means of palladium black and further investigation ought to be carried out with a view to determining definitely the conditions under which it can be made active. It has been recently shown by E. B. Maxted[26] that hydrogen sulphide inhibits the absorbing efficiency of palladium black. Similar facts have been known for a long time in the case of various metallic catalysts, and probably the same causes influence the behavior of palladium black.

[26] Journ. Chem. Soc. *115*, 1050 (1919).

(To be continued)

A New Form of Sectional Drive for Paper Machines

By W. W. Cronkhite, W. L. Merrill and H. W. Rogers
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A striking feature of the installation described in this article is the fact that an immense sum of money was spent for the construction of a paper machine that was wholly dependent for operation upon a system of drive that had never been applied to regular commercial production. Existing forms of drives could not be used satisfactorily at the high speeds involved. The merits of the system proposed by the electrical manufacturer were so obvious that the paper manufacturer was willing to place the order for the paper machine on the former's guarantee that the electrical equipment would perform the functions required of it. The installation is in every way a success; and thus again has electricity performed a task that was impossible by other means. Editor.

The driving of paper machines presents a number of problems that are peculiar to the process, and this matter has been the subject of much study by paper mill engineers for many years. In making paper we have to deal with a continuous web which starts over the machine containing approximately 1 per cent stock and 99 per cent water and comes out as a finished product approximately 95 per cent solid stock and 5 per cent moisture. Consequently very close speed control must be maintained throughout the machine, which is usually divided into at least eight separate and distinct sections. In addition, it is necessary that the motive equipment permit of speed adjustment for the whole machine over a wide range, often as great as 10:1. The drive must also be designed to permit of individual speed adjustment of each section at all times to take care of a certain amount of stretch and draw in the paper as it passes from section to section of the machine. This stretch and draw varies from time to time due to stock, atmospheric and steam conditions.

For years steam engines with mechanical speed changing devices, belts, cones, gears and clutches have been used for driving paper machines and this form of drive is still used extensively on smaller machines. In the past two years the demand for higher speeds and larger machines has created the necessity of finding a new method of applying power to a paper machine, in order to eliminate the instability of the belt and cone drive resulting from load changes, belt stretching, etc., and also to provide a method other than the use of clutches for starting the heavy dryer sections.

The electrical operation of paper machines during the past has practically been confined to the use of a single unit, either belt or direct-connected to the variable speed line shaft, the speed range being obtained by a combination of voltage and field control on the motor, which was driven from a generator usually belted to the constant speed shaft or direct to the steam engine driving the constant speed shaft. Where steam engines were not used this generator formed a part of a synchrorous motor-generator set, which was operated from the mill circuit. The adjustment of the draw and starting of the various sections of the machine are accomplished in the same manner as with engine drive, that is, by cones, belts and clutches.

In order to visualize the problem of applying a sectionalized drive to a paper machine the diagram, Fig. 1, should be studied. *A* represents one of the dryer sections of the machine, consisting of a cylinder 5 ft. in diameter, 168 in. long, weighing 150 tons,

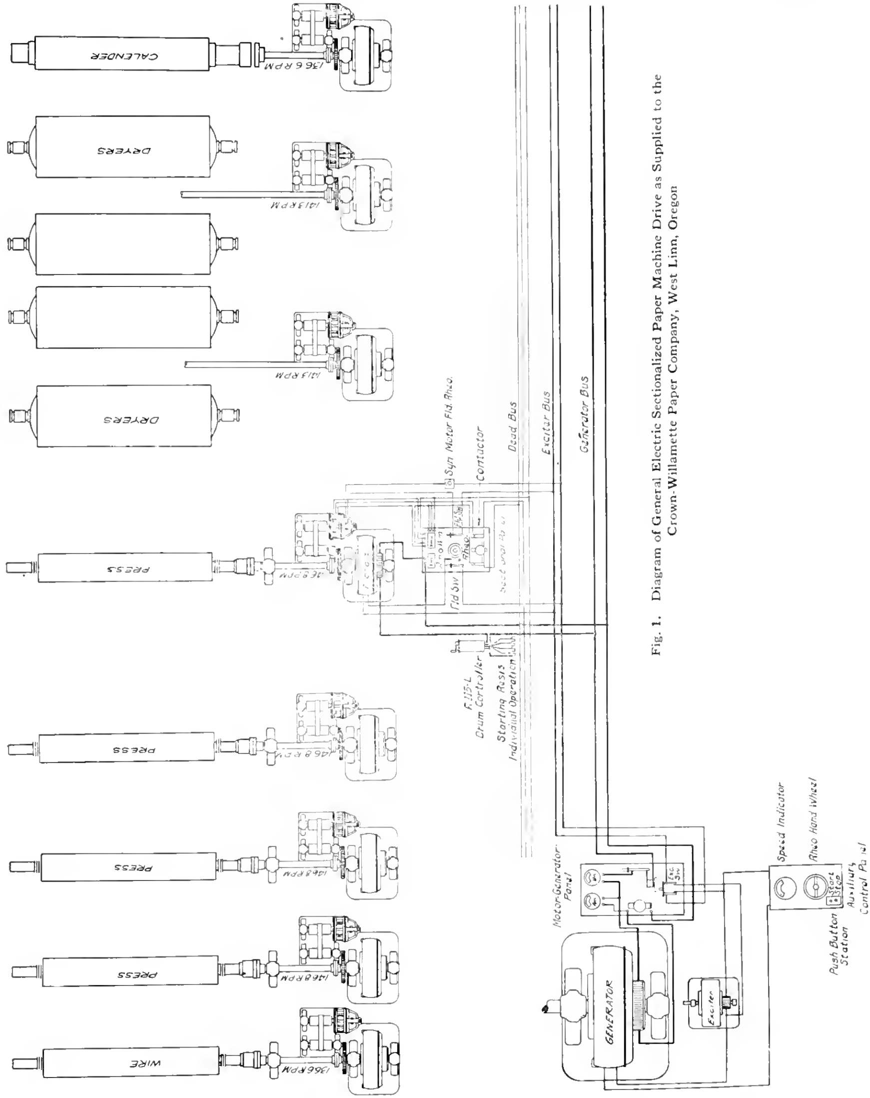

Fig. 1. Diagram of General Electric Sectionalized Paper Machine Drive as Supplied to the Crown-Willamette Paper Company, West Linn, Oregon

with the weight concentrated at the periphery, and running at a peripheral speed up to 1000 f.p.m. with a friction load varying from 20 to 30 h.p. *B* represents another section of the machine, which may be one of the presses 28 in. in diameter with practically zero WR^2,

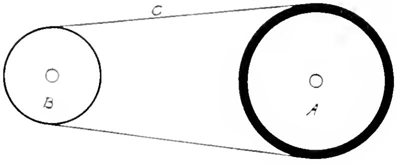

Fig. 2. Illustrating Problem of Sectionalized Paper Machine Drive

and a friction load varying from 30 to 65 h.p. according to adjustment of the weights.

The speeds of *A* and *B* must be relatively uniform under all of these conditions and in addition must be capable of an infinite number of adjustments throughout a small range for either section. Under these conditions the problem amounts virtually to belting these two sections together with a sheet of paper approximately 50 per cent dry, with belt centers varying from 1 ft. to 11 ft., and to drive each section with a separate motor continuously without breaking the paper *C* by a change in speed of the sections. To still further complicate the problem the average machine has at least eight sections and some machines have as high as eleven.

Therefore the most obvious method of accomplishing this drive is to rigidly tie together the various sections so that when the load changes on any section it will be reflected through and be absorbed by the whole machine; thus the speed of that particular section is not permitted to change due to change in load and the need for subsequently readjusting the speed by means of motor-driven rheostats or other regulators is obviated.

A new form of sectionalized motor drive for paper machines has been developed by the General Electric Company in which full consideration has been given to these requirements. Each section is driven by an independent motor, the speed of which with relation to the speed of the other sections may be regulated to suit the requirements, and when once adjusted will retain this relationship as positively as though geared together.

A typical form of this new drive has been supplied to the mills of the Crown-Willamette Paper Company, West Linn, Oregon. The paper machine which consists of nine sections is employed in the manufacture of newsprint and is designed for high speed operation, producing paper 164 in. wide at a rate of 1000 ft. per minute. The first section, known as the Fourdrinier end, receives the stock in

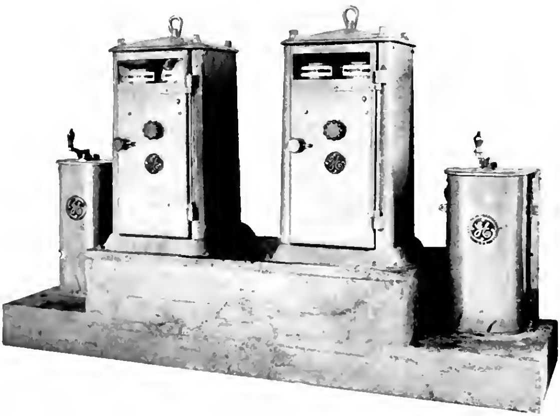

Fig. 3. Reel and Calendar Protective Panels and Controllers

liquid form and delivers it to the first press. There are four other press sections which still further reduce the moisture content. Next in sequence are the dryer sections which dry the paper as it is received from the presses. The next section is the calender stack, which puts the finish on the sheet. The last section is the reel, which winds the paper in rolls and must synchronize with the rest of the machine.

The main power supply for this machine consists of a 1000-h.p., 3600-r.p.m. geared turbine driving a 600-kw., 250-volt, 900-r.p.m. direct-connected generator and exciter. Eight sections of the paper machine are each equipped with a 100-h.p., 136-r.p.m. shunt-wound motor direct coupled, while the reel is driven by a direct coupled motor of 30 h.p. These nine motors are supplied with power on a Ward Leonard system from the turbine generator, and the speed of the machine as a whole is controlled by the voltage of this generator, the fields of the motors being excited from the same excitation source as the generator. The motors have the same speed regulation from no load to full load. The sections are started and stopped by means of drum controllers and protective panel, shown in Fig. 2.

The novel feature of the installation consists of 20-h.p. synchronous motors, one of which is mounted on the base of each of the direct-current motors and is connected to the main motor by means of a fabroil gear and a pair of cones belted together with an 8-in. double ply belt. The function of these synchronous motors is to rigidly tie together the various sections of the paper machine and maintain a positive unvarying speed relation between them.

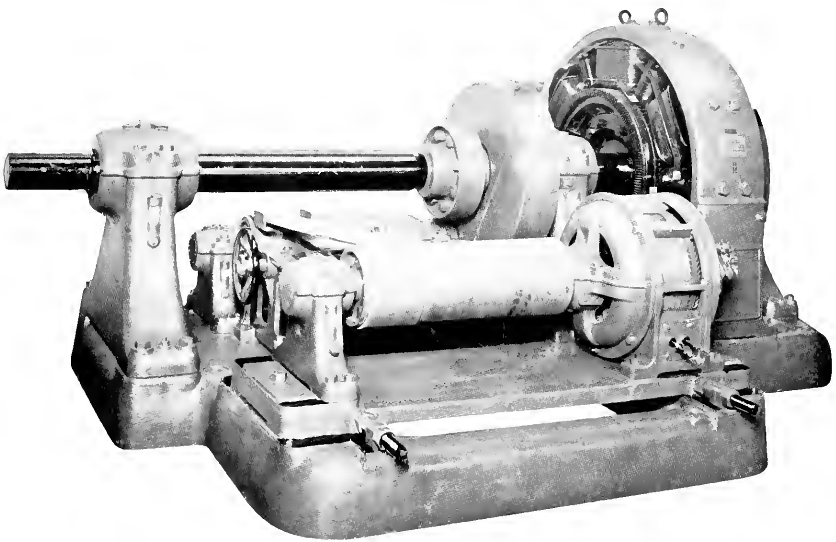

Fig. 4. One of the Motor Units for Sectionalized Drive of Newsprint Machine at the Mills of the Crown-Willamette Paper Company, West Linn, Oregon. Nine of these units are employed to drive the various sections of the paper machine

In the ordinary operation of making paper it becomes necessary to increase or decrease the load on some particular section as conditions vary, and the function of these synchronous machines is to absorb this change in load and distribute it over the entire machine, thus preventing the change in load on the section from varying the speed of the direct-current motor coupled to it. This is accomplished by connecting all the synchronous machines to a dead bus.

Assume that the machine is running under normal conditions and that the belts are in the proper position on all of the synchronous machines but one for maintaining the desired draw (speed difference between sections), and that the operator desires to increase the speed of the one section without disturbing the rest of the machine. The procedure is as follows: The handwheel which operates the belt shifter on the cone pulleys is turned in the proper direction until the desired speed is obtained.

Shifting the belt in this case tends to slow up the synchronous machine, but since its speed cannot be altered it assumes a portion of the load and draws power from the dead bus, each of the other synchronous machines functioning as generators to supply the power. The synchronous motor thus relieves the load on the direct-current motor of this particular section and the latter motor speeds up accordingly.

Now by slightly weakening the field of the main driving motor a flux condition is established which transfers the load from the synchronous motor to the main driving motor without changing its speed.

Slowing down any section is of course effected in a manner the opposite of this, the synchronous machine in this case serving as a load brake on this particular direct-current motor by acting as a generator and delivering the power to the dead bus, which is equally absorbed by the remaining eight machines.

From this description of the method of changing the speed of any section it is evident that any change in load inherent in the operation of the machine, such as would result from changing weights on the presses, increasing the suction on the wire, or particularly the transfer of a part of the load of the last dryer section to and from the calender stack due to the tendency of the stack to pull the dryers, is absorbed by the motors of the entire machine and hence no backing up of the dryers occurs when the paper breaks between the dryers and the calender. No action is necessary by the operators to correct this condition which is inherent in mechanically driven machines. These machines are of ample capacity to take care of these various changes without adjustment of the rheostats.

There are many other advantages incidental to this drive, in particular the ability to slow down any or all of the presses during the wash-up period, and the very slow speed of a few feet per minute for inspecting the wire, for spotting the dryers for sewing tears, and for putting on new dryer jackets and carrier ropes. The reversible feature of the drive also is of advantage in handling the clothing on the dryers as well as in backing up the calender stack when it accidentally becomes plugged.

One of the novel features of this drive is its adaptibility to very low speed machines with direct-connected motors, by which are eliminated the maintenance and attendance troubles that could be expected if intermediate reduction gears were interposed between the motor and the intake shaft. On one of these drives which the General Electric Company is now supplying the motors are designed for operation at 15 r.p.m. and in tests made at the mill of the Crown-Willamette Company no trouble was experienced from unstableness, even with the machine running at a paper speed of 75 ft. per min., which is a corresponding motor speed of 10.2 r.p.m.

The credit for the initial installation belongs to A. J. Lewthwaite of the Crown-Willamette Paper Company, and Stewart D. Lansing of the Badgley & Sewell Company, who were quick to realize the possibilities of this method of drive Their sound judgment has been amply substantiated by the unqualified success of the equipment.

Besides the installation at West Linn, the General Electric Company is building eleven more of these equipments for some of the largest paper companies in the United States and Canada. One of these is for a news machine, which will make paper at 1200 r.p.m.

Other paper machine drvies include equipments for book machines with a speed variation of 6:1. These will be 196-in. machines, the largest book machines in the world, and will make paper from 100 to 600-ft. per min. with an ample margin below this for wire inspection, adjustment of clothing, etc.; this entire range being obtained by the adjustment of a single rheostat conveniently located.

Stress Determination by Means of the Coker Photo-elastic Method

By A. L. Kimball, Jr.
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The optical system of the apparatus used for determining stress by polarized light is analyzed in the following article and an explanation is given of the operation of a polarizing prism and of the quarter wave plate. The nature of stress and how it influences polarized light is briefly considered with an explanation of the color effects produced. A proof of the quantitative law of variation of light intensity with stress for one color is given for the standard set-up of the apparatus.—Editor.

Introduction

The Coker Photo-elastic Method as instituted at the General Electric research laboratory affords a means of direct measurement of stress in any ordinary member in which the stresses lie in one plane. This is accomplished by the use of polarized light and extensometer measurements made on transparent models of nitro cellulose.

The general method, the apparatus used and various applications are described in the series of articles by Dr. Coker which are being published in current numbers of the General Electric Review.

In this article it is proposed to consider a particular aspect of the subject in some detail, namely, the optical theory involved, whereby definite stresses produce definite colors.

Fig. 1 shows the optical apparatus used and Fig. 2 a diagrammatic representation of the set-up and of the path of the light rays.

General Description of Apparatus

Light from a source A (Fig. 2) passes through a condensing lens B and water screen C (to reduce the heat rays) and is then passed through a polarizer D. This unit consists of two 4½-in. condensing lenses and two small concave lenses arranged as shown in Fig. 3 in combination with a Nicol polarizing prism of Iceland spar. The latter is of less than one

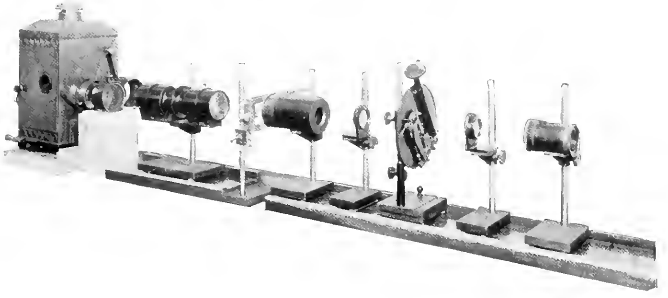


Fig. 1. Optical Apparatus

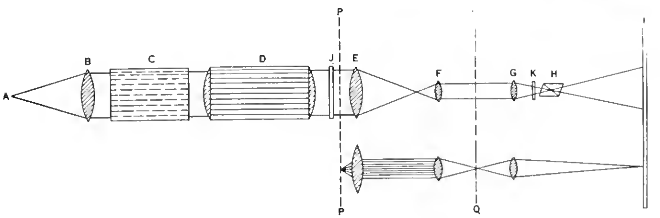


Fig. 2. Schematic Diagram of Optical Set

inch circular aperture, but with the combination of lenses gives a 4½-in. beam of polarized light. We thus have accomplished substantially what a Nicol prism of 4½-in. circular aperture would do were there any of that size obtainable. The plane polar-

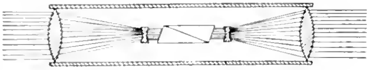


Fig. 3. Palarizer D, Fig. 2

ized light is then passed through a quarter wave plate of mica, J, which alters it to circularly polarized light, which in turn is passed through the transparent specimen under examination to which is applied the required stress. This specimen is in the plane marked P, the light passing normally through it. The light then passes through lenses E, F, and G and through the quarter wave plate K which is similar to J except that its axis is at 90 deg. to that of J, and therefore counteracts the effect of J. The resulting light is analyzed by the polarizer H with its plane of polarization 90 deg. to that of the polarizer D. The light is finally projected upon the screen I so that points in either the plane P or Q, in whichever the specimen is placed are brought to a focus on this screen (see Fig. 2). The colors produced depend directly on the stress distribution in the specimen.

Detailed Statement of Theory

After passing through the condensing lens, which gives an approximately parallel beam, and a water screen, the light passes through the polarizer as described which contains a polarizing Nicol prism of Iceland spar. Iceland spar is a crystalline form of $Ca\ CO_3$, often called calcite, which has the peculiar property of transmitting light waves whose vibrations are parallel to a particular direction in the crystal, called the optic axis, with greater velocity than vibrations perpendicular to this axis. When a ray of light passes into the crystal as shown in Fig. 4, in a plane parallel to the optic axis (the cross hatching being parallel to the optic axis), this ray is separated into two rays which obey different laws of refraction and consequently are bent through different angles on entering the crystal, as shown in Fig. 4. The light, before it entered the crystal, consisted of a complex vibration transverse to its direction of motion (Fig. 5), but on entering the spar all components of this vibration lying in a plane parallel to the optic axis must be transmitted at a higher velocity than those perpendicular to it. This is because vibrations in this plane have a component parallel to the optic axis, and these vibrations, as stated above, will be transmitted at a greater velocity than vibrations perpendicular to this axis. Therefore it comes about that the vibrations in this plane are transmitted faster than those perpendicular to it, and when the optic axis is at an angle, as shown in Fig. 4, they travel at a different angle from vibrations perpendicular to this plane because the refractive index for one set of vibrations is different from that for the others. They are thus separated out as a different ray which is known as the extraordinary ray. The vibrations which are perpendicular to the principal plane, and have no component parallel to the optic axis, and thus are transmitted as though there were no optic axis, constitute what is known as the ordinary ray. Both extraordinary and ordinary rays, however, must execute vibrations in only one direction each, the former in the phane parallel to the optic axis and the latter perpendicular to it. In Fig. 4 the extraordinary ray executes vibrations in the plane of the paper and the ordinary perpendicular to it. These rays are said to be polarized, and are polarized in planes at right angles to each other. In the case shown in Fig. 4, the ordinary ray is bent more than the extraordinary. Fig. 4 also shows how such a piece of Iceland spar is made into a polarizing prism, called a Nicol prism after the name of its inventor. The crystal is cut in half along the plane AB and sealed together again with a layer of Canada balsam. For the angle used, Canada balsam transmits the extraordinary ray, but totally reflects the ordinary ray which passes out to

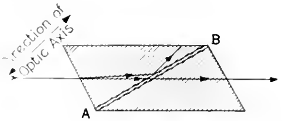


Fig. 4. Nicol Prism

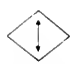


Fig. 4A. Direction of Vibration of Transmitted Light

one side and is absorbed by a black surface. Therefore the Nicol prism transmits polarized light, vibrating in the plane of the paper in Fig. 4. Fig. 4A shows the direction of vibration when looking at the diamond shaped end of the prism. To change the direction of vibration, it is only necessary to revolve the prism to a new position.

Fig. 5 shows a ray of light with its random transverse vibrations on the entering side of the Nicol prism, and emerging on the farther side as a ray of plane polarized light, in this case vibrating in a plane at 45 degrees to the horizontal.

Light of this sort emerges from the polarizer D (Fig. 2), but before passing into the sample to be tested, which is placed in the plane P or Q, it is made to pass through a quarter wave plate J. This is a plate cut from a crystal, usually of quartz or mica (mica in this case), which is so placed that the vibrations of the plane polarized ray are changed from a plane vibration to a circular one, in which case the light is said to be circularly polarized. A quarter wave plate is made of a so-called doubly refracting crystal, like Iceland spar in its action on light. A thin plate of crystal is cut with its optic axis parallel to the plate. Vibrations parallel to this axis travel with a different velocity from those perpendicular to it, giving extraordinary and ordinary rays again, executing vibrations in directions at 90 deg. to each other. In Fig. 6, AB represents the optic axis. The emergent ray is shown as two components, the extraordinary vibrating in the horizontal and the ordinary in the vertical plane. Here, however, where the incident light is perpendicular to the optic axis and to the surface of the plate, no bending of either ray results, but one travels faster than the other, or one is retarded more than the other as it is usually stated, as both are retarded with respect to the velocity of light in air. The difference in retardation of these two vibrations depends on the distance of transmission, or the thickness of the plate. The quarter wave plate is cut of such a thickness that one of these waves is retarded a quarter of a wave length with respect to the other. Thus any ether particle at say P, Fig. 6 (since it is

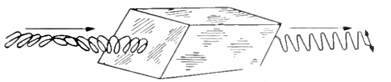


Fig. 5. Effect of Nicol Prism on Light Vibration

the ether which transmits light vibrations), is made to vibrate up and down and sideways at the same time, and if one wave train is a quarter of a period behind the other, the resultant vibration is a circular one, and we have circularly polarized light. This is exactly analogous to the case of two pulsating magnetic fields at 90 degrees in space phase and a quarter of a wave length apart in time phase, giving a resultant revolving magnetic field.

To get a separation into these two perpendicularly polarized rays the direction of

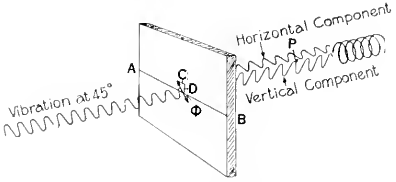


Fig. 6. Action of Quarter Wave Plate on Light Vibration

vibration of the incident light must make an angle with the axis AB (Fig. 6) such that neither C nor D vanish. For vibrations C and D to be of equal amplitude this angle must be 45 degrees. It is only when these components are equal that they combine to make circularly polarized light when retarded relatively a quarter of a wave length, otherwise the light will be elliptically polarized, and when angle ϕ becomes zero or 90 deg. the light remains unaltered as D or C respectively vanishes. Thus to produce circularly polarized light the direction of vibration of the incident light must make a 45 deg. angle with the axis AB described above. It is seen that the plate may be placed at four different angles 90 deg. apart to produce circularly polarized light. If the axis AB shown in Fig. 6 is changed to the vertical position the direction of vibration of the incident ray still makes a 45 deg. angle with this axis, but the relative retardation of the horizontal and vertical vibrating emergent rays is reversed in sign. For instance, instead of the horizontal vibration being retarded with respect to the vertical, the vertical is retarded with respect to the horizontal vibration. The result of this is that the circular vibration of the polarized beam takes place in a reversed sense, clockwise becoming counterclockwise, and vice versa. Thus, to reverse the direction of vibration in a circularly polarized beam produced by a quarter wave plate, rotate the plate through 90 deg. in its plane. Also, it may be stated that polarized light transmitted through two quarter wave plates with axes at 90 deg. remains unaltered, the effect of one plate being neutralized by the other. The quarter wave plate K in Fig. 2 is used to cancel the effect of J, its axis thus making 90 deg. with that of J. No change is produced in the effect of a quarter wave plate if it is reversed so the light passes through it in the opposite direction provided the axis is placed in the same direction.

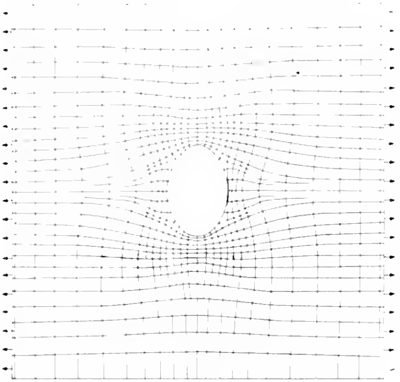


Fig. 7. Principal Stress Lines About an Elliptical Hole in Tension Member

Quarter wave plates are commonly made of quartz or of mica. Mica is used for large plates and is used for this set of apparatus. Mica is a so-called biaxial crystal, but it affects light exactly as described, where the faces of the plate correspond to the ordinary cleavage planes of the crystal.

It is seen from this discussion that the polarizer D (Fig. 2) must be placed so that the plane of polarization of light produced by it is at 45 deg. to the axis of the quarter wave plate J to give circularly polarized light. It is circularly polarized light which is passed through the transparent model under stress in the plane P.

Before considering the action of the stressed member on the incident circularly polarized light, a few remarks will be made about plane stress in general in a homogeneous medium. Every system of plane stress, or stress whose directions all lie in one plane may have these directions represented by a double system of curves intersecting at right angles at all points, just as for electricity flowing in a plane the equipotential lines and lines of direction of flow form such a system, only this case is represented by a different set of mathematical equations and is not generally comparable with the case of stress as is often supposed, except in very special cases. Such a system of *principal stress lines*, as they are called, is shown in Fig. 7 for an elliptical hole in a member under tension, the major axis of the ellipse being transverse to the direction of applied tension. These principal stresses intersect everywhere at right angles, and are always normal and tangent at boundaries where there are no applied stresses. These two systems of principal stresses are called the p and the q systems. At all free boundaries no normal stress can exist, so that either p or q must vanish, the tangential stress alone remaining. A special characteristic of these principal stresses is that their directions always coincide with directions of zero shear, and the shear at any point always has maximum values in planes at 45 deg. to the principal stress directions (see Fig. 7). The shear intensity varies according to the sine law from a maximum of $\frac{1}{2}(p-q)$ at 45 deg. to zero in the principal stress directions. These facts are generally true for any system of plane stress whatsoever in a homogeneous medium, and when once clearly seen will be a great aid in estimating stress distributions. For three dimensional stress the same laws also hold, with an extension to three dimensions, namely: (1) the principal stress directions are represented by three systems of lines at 90 deg. to each other; (2) at any bounding surface, where no applied forces exist one of these directions is normal and the other two coincident with that surface; (3) any plane coinciding with two of these stress directions is a plane of zero shear; (4) all planes at 45 deg. to these planes are planes of maximum shear; (5) the shear varies from a maximum in these 45 deg. planes to zero in the principal stress planes according to the sine law. Plane stress is simply a special case of this more general law. In the photo-elastic method as described here, however, we are concerned with only plane stress.

We are now in a position to consider the action of a plane stressed specimen of celluloid on the polarized light when placed in the plane P, Fig. 2. As in the case of the quarter wave plate the light may be thought of as being separated in two polarized components with vibrations at right angles, and in this case the directions of vibration coinciding with the principal stress mentioned above for any point in the specimen. (See Fig. 8.) These, it will be recalled, always intersect at right angles. Also, if the principal stresses are unequal, one of the vibrations is retarded with respect to the other, this relative retardation being proportional to the principal stress difference at the point considered. This is the law which connects the light effect with the stress. Mathematically it may be expressed as follows:

$$\text{Relative retardation} = c(p-q)t \qquad (1)$$

p = one principal stress
q = other principal stress
t = thickness of specimen
c = optical constant for material used.

Before discussing this law we will follow out the course of the light and see how the color effects on the screen are produced. We will first consider light of one wave length only, say red. When this light emerges from the stressed specimen the polarized components at right angles are retarded different amounts with respect to one another according to the law stated above, and therefore the emerging vibration is plane, circularly or elliptically polarized depending on the amount of relative retardation of the components. This is shown in Fig. 8. The incident light, it will be recalled, is circularly polarized. The various changes this vibration goes through for every eighth wave length relative retardation of the components is shown in Fig. 9. For whole wave length retardations the light vibrates just as the incident; for odd half wave lengths, $\frac{1}{2}\lambda$, $\frac{3}{2}\lambda$, $\frac{5}{2}\lambda$, etc., the vibration is circular but in the opposite direction to the incident. For odd quarter wave lengths the vibrations are plane polarized and odd eight wave lengths elliptically polarized. The reason for using circularly polarized light on the stressed sample is, that no matter what the principal stress directions are, the plane polarized components parallel to these directions, into which it is separated, must always be of equal amplitude. This is true because linear components of a circular motion at right angles to each other are always of equal amplitude. It therefore follows that no matter at what angle the specimen be turned in a plane perpendicular to the light direction, or what direction the principal stresses p and q take, the vibrations of the light emerging from the specimen are always of the same character and therefore like the forms shown in Fig. 9. The *angle* of the emerging plane and elliptically polarized light, however, does depend on the stress directions, and changes as the sample is rotated in its plane, or referring to Fig. 8, the two ellipses shown will turn as the sample is turned. It only remains to show that passing this light through the second quarter wave plate K, Fig. 2, and the polarizing prism H, results in an effect independent of the anglar position of the specimen ro-

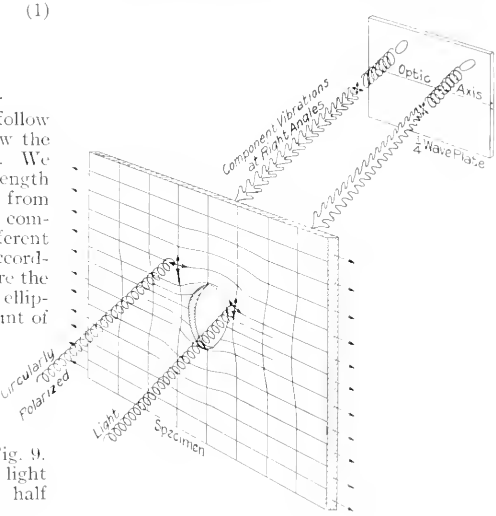


Fig. 8. Light Rays Passing Through Stressed Specimen

tated as mentioned above and of the principal stress directions. It is necessary, however, that the axis of this quarter wave plate be perpendicular to that of the first, and that the plane of polarization of the second polarizer be 90 deg. to the polarizing plane of the first, and 45 deg. to the axis of the quarter wave plates (see Fig. 10).

After transmission through the sample as explained above the light is of the character shown in Fig. 9, the directions of the component vibrations depending on the principal stress directions, but the relative retardations depending only on the difference in magnitude of the principal stresses for a specimen of given thickness according to the law previously stated in equation (1). When this light is transmitted through the last quarter wave plate and the second polarizer, the result is that for all points of the specimen where relative retardations of integral wave lengths (see Fig. 9) are produced the light is all cut out, for odd half wave lengths it is all transmitted, and the amplitude of vibration varies according to the sine law for intermediate points. The law is expressed mathematically as follows:

$$A = A_m \sin \pi\lambda \qquad (2)$$

where

A = amplitude
A_m = maximum amplitude
λ = relative retardation of vibration components in wave lengths.

Since the intensity of light varies as the square of the amplitude, we have

$$I = I_m \sin^2 \pi\lambda \qquad (3)$$

where

I = intensity of illumination
I_m = maximum intensity.

A proof of this law is given in the appendix to this article, as it is somewhat mathematical, though not difficult. The results are graphically expressed in Fig. 11. The positive and negative values of the amplitudes indicate an opposition of phase of the vibrations. All of the light transmitted through the second Nicol prism and projected on the screen is of course polarized in the same plane.

This discussion is for a single wave length, or monochromatic light only. If red light were used, the light projected on the screen would consist of a system of black and red bands depending on the stress distribution, the second and higher orders of red appearing where the difference between the principal stresses p and q was great enough. Where p and q were equal or where the stress was zero the red would all be cut out and black result. Black would also result where p and q differed by an amount which produced an even wave length relative retardation. For odd half wave length relative retardations, the maximum red would appear.

Exactly similar results are produced by any single wave length or color, but different colors are retarded different amounts by a given stress. The result is that the system of bands of one color do not exactly overlap those of another color, but are shifted with respect to each other, and for several colors the shifting results in repeated series of colors in place of what was a single bright and dark band in the case of single color. This is illustrated by Fig. 12, which shows a series of colors obtained from actual observation of a sample of celluloid 0.18 inches thick and 3/8 in. wide. The stress was carried up to 5000 lbs. per sq. inch. Four different colors are shown with their characteristic variations of intensity superimposed, which give a series quite approximately the same as the actual, and indicate the way the color series is produced. As p and q differ more and more this series of colors may pass through more than one order. The higher the orders of color, however, the greater the relative shift of different colors with a consequent dimming of the colors (see Fig. 12), remembering that white results from a superposition of all colors in equal intensity. As p and q increase in difference or as $p-q$ increases (see equation 1), the colors pass through a perfectly definite series. For celluloid this sequence is about as follows: beginning at ($p-q=0$ or $p=q$) black, straw, orange, red, blue green, and again straw, orange, red, blue green, etc. (See Fig. 12.)

The question now arises, Why is the color effect of particular value by itself if this sequence of colors is a measure of the difference $p-q$, and not of the values of p or q. For a complete determination of plane stress, $p+q$ is also determined from extensometer measurements as described by Dr. Coker. Only color observations are necessary, how-

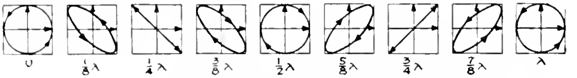


Fig. 9. Alterations of Circularly Polarized Light for Increasing Relative Retardation of Components

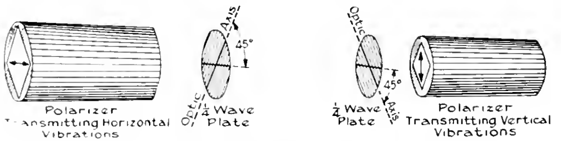


Fig. 10. Relations of Polarizing Planes of Polarizers and Axes Quarter Wave Plates

ever, where either p or q vanish. Now it will be remembered from the previous discussion of principal stresses, p and q, that they are always normal and tangent to free edges in plane stress, and furthermore, it is evident that there can be no stress normal to a free edge. Therefore at all free edges, p or q must vanish, and the remaining stress is single and tangent to the edge. Therefore, at all free boundaries in a plane stressed specimen the order of color is a direct measure of the stress magnitude. This fact is of particular value because edges are often regions of *maximum stress*. Thus, for such a case a color observation gives the maximum stress at once. For a simple rectangular tension member or for parts of a beam of uniform either in plane P or Q, Fig. 1. The color effects of two specimens may be readily superimposed, or a calibration specimen may be placed in one of the planes.

The color effect obeys the same law, whether p or q are positive or negative. Negative stress, of course, corresponds to compression. There are different ways, however, of distinguishing between the two, and ordinarily no difficulty is encountered.

If the quarter wave plates are removed the color effect is no longer a measure of the principal stress differences except where the principal stress directions are at 45 deg. to the planes of the crossed Nicols. Where these directions coincide with the planes of polarization of the Nicol prisms, the light is all cut

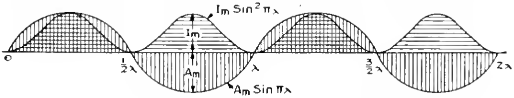


Fig. 11. Amplitude and Intensity of Transmitted Light Corresponding to Increasing Stress for One Color

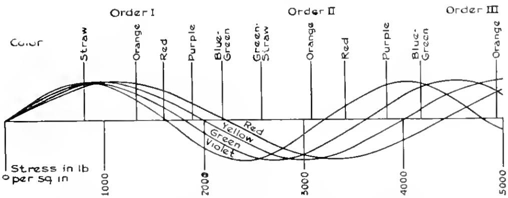


Fig. 12. Amplitude of Transmitted Light Corresponding to Increasing Stress for Several Colors Superimposed

cross section, there exists only one set of principal stresses, and here also the color gives the stress directly. The neutral axis of the beam may show as a dark band. For many cases, however, dark areas represent areas where p and q have finite values but are equal. These must be clearly separated from cases of zero stress. The stress magnitudes corresponding to particular colors can be read directly from the color. A sample of the same material as the specimen under investigation is taken and the various colors are calibrated in terms of stress. Another method, superior to the above for some purposes, is to balance out the color until a dark field is produced, using a piece of the same material on which the stress intensity is measured by a spring balance. This is described more in detail in Dr. Coker's articles. This is why the optical system is such that stressed samples may be placed out and dark bands on the screen mark the locus of such points. This is because when the light passes through the first polarizer it is transformed to plane polarized light with vibrations in one direction. If the direction of vibration coincides with a principal stress direction (see Fig. 8), the light is transmitted with no alteration, and is therefore completely cut out by the second polarizer which is so turned that it transmits only vibrations transverse to the direction of the first. If, however, the plane polarized light from the first prism is transmitted through a part of the specimen where the lines of principal stress are at 45 deg. to the direction of vibration, the vibration is separated into two equal components vibrating in directions at right angles to each other and one retarded with respect to the other. The result is that we obtain a color indication of stress for such points exactly as when the quarter wave plates were used. As the angle between the principal stress directions and the direction of vibration of the polarized light changes from 45 deg. the colors die out, with a black band corresponding to coincidence of direction of vibration with the principal stress directions. As the polarizers are rotated, but kept crossed with respect to each other these black bands shift, corresponding at every instant to the locus of points on the specimen where the principal stress lines and the planes of polarization of the Nicol prisms are coincident. This gives a means of mapping out the principal stress directions for any plane stressed model of the transparent material used.

The optical measurements therefore give the principal stress differences and their directions at all points in a plane stressed specimen. Where p or q vanishes, as must take place at all free edges, which are often points of maximum stress, the color alone will give the stress magnitude. P or q may also vanish at interior points for certain simple systems as in some cases of a rectangular beam and tension members of uniform cross section. Therefore, in many practical cases the color measurements are sufficient.

For determinations of stress magnitudes at *all* points in a plane stressed specimen, extensometer measurements of transverse contractions are made, giving a measure of $p+q$ to supplement those of $p-q$, and p and q may then be found at all points.

APPENDIX

Given a general case of elliptically polarized light: To find the laws according to which the intensity of monochromatic light varies when transmitted through a quarter wave plate and a polarizing prism with its axis at 45 deg. to that of the quarter wave plate.

In Fig. 13, PQ represents the line of vibrations transmitted by the polarizer which is at 45 deg. to the axis of the quarter wave plate shown to one side. An elliptical vibration path is shown and the component vibrations OA and OB of which it is composed. We will regard OA as retarded with respect to OB, the amount of this retardation determining the form of the elliptical motion of which the circle and straight line are limiting cases.

Expressing the amplitudes of these vibrations OA and OB in terms of components perpendicular and parallel to the optic axis of the quarter wave plate, or along the X and Y axes as shown in the figure, we obtain

$$\overline{\mathbf{OA}} = \mathbf{i}\, a\, cos\left(\frac{\pi}{2}+\phi\right)+\mathbf{j}\, a\, sin\left(\frac{\pi}{2}+\phi\right)$$

$$= \mathbf{i}\, cos\left(\frac{\pi}{2}+\varphi\right)+\mathbf{j}\, sin\left(\frac{\pi}{2}+\phi\right) \qquad (1)$$

when a = 1.

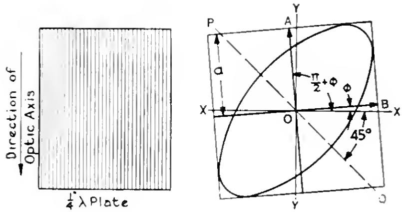


Fig. 13

This is a vector equation, **i** being a unit vector parallel to the X axis and **j** being a unit vector parallel to the Y axis. Vector quantities are shown in heavy type. The quantity multiplying these vectors is their length.

In like manner:

$$\overline{\mathbf{OB}} = \mathbf{i}\, cos\ \varphi+\mathbf{j}\, sin\ \varphi \qquad (2)$$

(1) and (2) give the amplitude of the vibrations OA and OB. To express the fact that these vibrations vary with time according the sine law we obtain

$$\overline{\mathbf{OA}}\, sin\,(\omega t-\theta_1) = \left[\mathbf{i}\, cos\left(\frac{\pi}{2}+\phi\right)+\mathbf{j}\, sin\left(\frac{\pi}{2}+\phi\right)\right][sin\,(\omega t-\theta_1)] \qquad (3)$$

$$\overline{\mathbf{OB}}\, sin\ \omega t = [\mathbf{i}\, cos\ \phi+\mathbf{j}\, sin\ \phi]\, sin\ \omega t \qquad (4)$$

where

ω = angular velocity of the time vector

and

θ_1 = angular lag of $\overline{\mathbf{OA}}$ with respect to $\overline{\mathbf{OB}}$

The elliptical vibration is the path traced by the vector sum of these two components:

$$\mathbf{r} = \left[\mathbf{i}\, cos\left(\frac{\pi}{2}+\varphi\right)+\mathbf{j}\, sin\left(\frac{\pi}{2}+\varphi\right)\right][sin\,(\omega t-\theta_1)] + [\mathbf{i}\, cos\ \phi+\mathbf{j}\, sin\ \phi]\, sin\ \omega t \qquad (5)$$

This is the path traced by the tip of the vector **r** drawn from 0 as it swings around. Now this motion is altered in two ways, first by passing through the quarter wave plate, and second, by the rays passing through the polarizing prism.

When it passes through the quarter wave plate all the components parallel to its optic axis, or the **j** components are shifted in phase by $\frac{1}{4}\lambda$ or $\frac{\pi}{2}$. In this case we will assume a retardation.

Taking account of this, (5) becomes

$$\mathbf{r}=\mathbf{i}\,cos\left(\frac{\pi}{2}+\phi\right)[sin\,(\omega t-\theta_1)] +\mathbf{j}\,sin\left(\frac{\pi}{2}+\phi\right)\left[sin\left(\omega t-\theta_1-\frac{\pi}{2}\right)\right] +\mathbf{i}\,cos\,\phi\,sin\,\omega t+\mathbf{j}\,sin\,\phi\,sin\left(\omega t-\frac{\pi}{2}\right) \quad (6)$$

The vibration represented by (6) is again altered by transmission through the Nicol prism. This selects all components parallel to PQ, superimposes them upon each other and rejects all transverse components. Projecting the component vectors of (6) upon PQ, dropping the unit vectors and remembering that the projections of the **j** components are negative, we obtain

$$r\sqrt{2}=cos\left(\frac{\pi}{2}+\phi\right)sin(\omega t-\theta_1)-sin\left(\frac{\pi}{2}+\phi\right)\left[sin\left(\omega t-\theta_1-\frac{\pi}{2}\right)\right] +cos\,\phi\,sin\,\omega t-sin\,\phi\,sin\left(\omega t-\frac{\pi}{2}\right) \quad (7)$$

Transforming and simplifying, we obtain

$$\begin{aligned} r\sqrt{2}&=(-sin\,\phi\,cos\,\theta_1+cos\,\phi\,sin\,\theta_1+cos\,\phi)\,sin\,\omega t\\ &\quad+(sin\,\phi\,sin\,\theta_1+cos\,\phi\,cos\,\theta_1+sin\,\phi)\,cos\,\omega t\\ &=(-sin\,(\phi-\theta_1)+cos\,\phi)\,sin\,\omega t\\ &\quad+(+cos\,(\phi-\theta_1)+sin\,\phi)\,cos\,\omega t\\ &=A\,sin\,\omega t+B\,cos\,\omega t \end{aligned} \quad (8)$$

The amplitude of this vibration

$$=r_m\sqrt{2}=\sqrt{A^2+B^2}=\sqrt{2+2\,sin\,\theta_1}$$

$$r_m=\sqrt{1+sin\,\theta_1} \quad (9)$$

where

r_m = maximum value of r.

Therefore the amplitude of the transmitted light is dependent on the relative retardations of OA and OB only and independent of the angle ϕ. We have thus proved that changing the angular position of the specimen does not alter the transmitted light intensities.

Now θ_1 is the retardation of the *first* quarter wave plate plus that of the specimen, or $\theta_1=\theta_2-\frac{\pi}{2}$ where θ_2 = retardation due to specimen alone. The sign is negative because the axis of the first quarter wave plate is at 90 degrees to that of the second. Substituting for θ_1 we have

$$sin\,\theta_1=sin\left(\theta_2-\frac{\pi}{2}\right)=-cos\,\theta_2$$

or from (9)

$$r_m=\sqrt{1-cos\,\theta_2} \quad (10)$$

But $\theta_2=2\pi\lambda$ where λ = retardation of one component behind the other in wave lengths

$$r_m=\sqrt{1-cos\,2\pi\lambda}=\sqrt{2}\,sin\,\pi\lambda \quad (11)$$

where in Fig. 13, $a=1$.

We thus obtain the following result:

(1) The amplitude of the transmitted light is independent of ϕ or of the direction of the principal stress lines.

(2) It depends upon the relative retardation of OA with respect to OB according to the sine law.

Negative values of amplitude mean a reversal of phase of the plane polarized light.

The intensity of illumination is proportional to the square of the amplitude, or

$$I=I_m\,sin^2\,\pi\lambda \quad (12)$$

Where I_m = maximum value of the intensity.

For a graphical representation of the results see Fig. 11.

Photo-elasticity for Engineers

PART III

By E. G. Coker, D.Sc., F.R.S.

Professor of Engineering in the University of London, University College

Written specially for General Electric Review

In this article Dr. Coker discusses the photo-elastic investigation of the testing of materials in tension. It is shown that if the enlarged ends of a test bar are connected with the parallel part by arcs of a circle the stress near the join of the arc with the parallel portion is somewhat greater than that in the parallel portion. This is marked if the radius of the arc is small and approaches a right angle. Taking the special case of the British standard test bar for plates, it was found that in the most unfavorable case this maximum value was about 20 per cent above the stress in the bar between the enlarged ends. A cylindrical bar showed the same effect and this maximum value of stress is suggested as the reason why in many cases test pieces fail at the enlargement of the parallel portion.—Editor.

Photo-elastic Investigations on the Testing of Materials in Tension

Among the tests which engineers have adopted for finding out the properties of the materials they use in construction the one which finds most favor is a tensile test over the whole range of stress to fracture, since by such means it is possible to form a very accurate idea of the value of the material for use. The results, if care is taken, are practically independent of the testing machine employed, while the simplicity of the test makes it very generally useful for comparing different materials.

There are, however, circumstances which may make this form of test less simple than might at first sight appear owing to the possibility of the occurrence of a variable distribution of stress in the member from causes which appear to have been only imperfectly realized.

The application of load to a flat bar or cylindrical specimen, by the usual forms of grips employed, is practically always accompanied by a variable distribution of stress at and near the ends, and in order to prevent fracture there it is usual to increase the sectional area of the ends of a test piece, while the manner in which the change of section is made between the ends and the central part of the specimen is provided for in standard specifications to ensure uniformity of stress within the gauge length. There is, however, a lack of definiteness in some of the provisions of these specifications which make it possible, in certain cases, for variable stress to occur in the gauge length owing to the form of the discontinuity at the ends and it is the object of the present article to briefly describe some photo-elastic investigations which have been made recently on standard test bars, and the results of which were published in the Minutes of the Proceedings of The Institution of Civil Engineers.

For plane stress it has already been shown on theoretical grounds and verified independently by experiment that loaded transparent models, with one boundary, give distributions of stress precisely similar to those of the actual element loaded in the same manner; and although in the experiments to be described it has been considered advisable to check the results obtained on transparent models by an occasional experiment on a metal test piece, the bulk of thedata has been obtained by optical means on account of the ease and accuracy of measurement which such methods allow.

The primary form of a standard test bar for plates may be derived from the simple

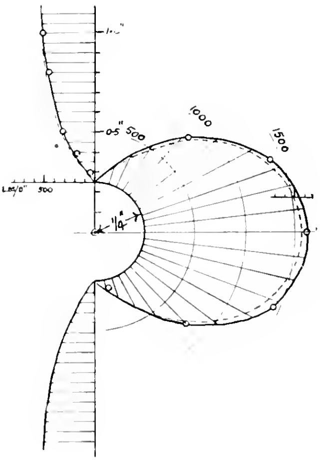
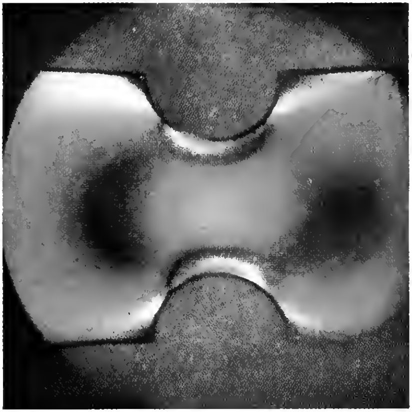
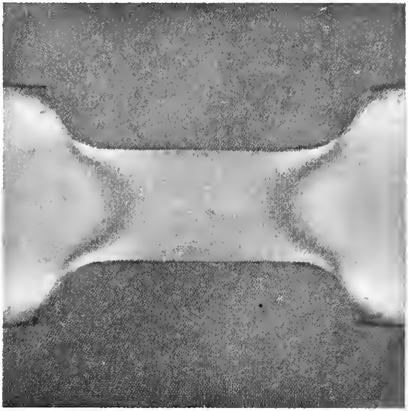


Fig. 2

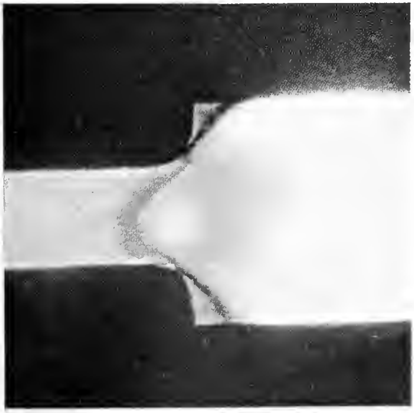
case of a uniform strip having two semicircular notches in it symmetrically disposed with reference to the axial line. Indeed such a form has occasionally been used for tension experiments, although, as Fig. 1A shows, there is no uniform stress distribution at or

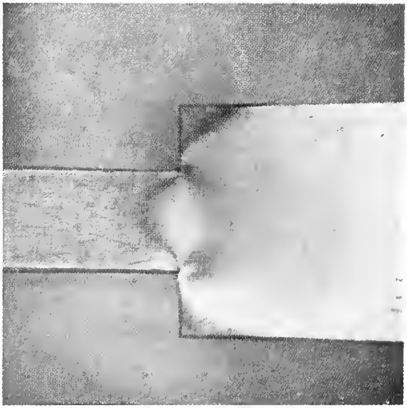


(A) Tension member with two semicircular notches



(B) Tension member of approximately two units width connected to ends of four units width by quadrantal arcs of one unit radius.





(C) and (D) Two views of a tension member, the effect of varying the radius of the connecting arcs

Fig. 1. Tension Members Under Stress

near these notches and the material is subjected to a somewhat complex stress which never approaches pure tension unless the notches are of insignificant dimensions.

Across the minimum section there is, in fact, a highly variable tension accompanied by a variable cross-stress which is not insignificant. In a tension member of this kind 1 in. wide with notches of $\frac{1}{4}$-in. radius a mean applied stress of 1092 pounds per square inch across the minimum section produced a stress d of 1580 pounds per square inch at the ends which fell to about one-half this value at the centre and was accompanied by a variable cross Q which rose to a value of 250 pounds per square inch near the ends of the section and diminished somewhat towards the center. The actual measurements are shown in Figs. 2 and 3 which also show the stress developed at the contours. A close approach to uniform stress is only obtained in this case at a distance of 4R from the minimum cross section, where R is the radius of the notch. As might be expected, the variability of stress round the semicircular notch is even greater because the right angled corners are not stressed at all, under any load, as is apparent when the specimen is viewed in a polariscope. Notches of $\frac{3}{16}$-in. and $\frac{1}{4}$-in. radius cut in the same tension member give somewhat similar results, and as might be expected the center of the minimum cross section becomes more evenly stressed as the notches decrease in size. In all these cases the effect of cross stress is always apparent. In a metal specimen precisely similar distributions have been observed by my former research student, Mr. Y. Satake, who showed

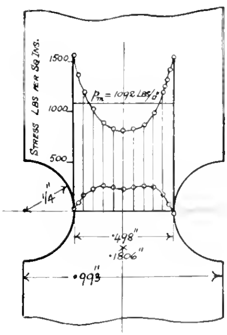


Fig. 3

that a notched steel specimen intermediate between the two latter cases gives a stress distribution curve across the minimum section which lies between similar curves obtained from the transparent models when due account is taken of the actual loads applied.

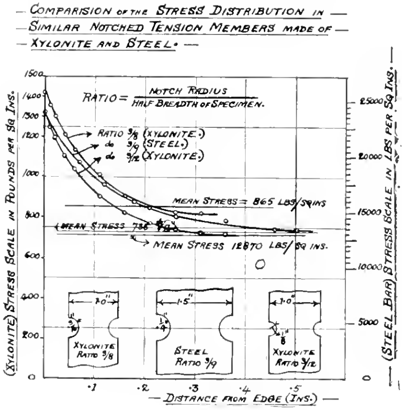


Fig. 4

The basis of comparison here is necessarily the sum of the principal stresses $(P + Q)$, since there seems no easy way of separating P from Q for a metal specimen. These curves are shown in Fig. 4, together with the actual forms of each test bar, and they afford a further confirmation of the applicability of photo-elastic measurements to engineering materials.

Although the form of this test piece is simple, its shape has, up to now, eluded mathematical analysis of the stress distribution except by an approximate method due to Leon for the case of a single notch in a very wide plate. This solution when applied to a tension member with symmetrical notches of moderate size, agrees fairly well with the measurements obtained at the minimum cross section, although the analysis is defective especially as regards radial stress around the notch

The tensional stress p across the minimum section in all these cases, agrees fairly close with the following relation derived from the analysis

$$p = f\left(\frac{a^4}{v^4} + \frac{a^2}{v^2} + 2\right)$$

where t is the stress corresponding to an infinitely wide plate, a is the radius of the notch and r is the distance of any point on the line of the minimum section between the notch boundary and the line of pull.

If we compare this formula with the average stress p_m it is easy to derive an approximate

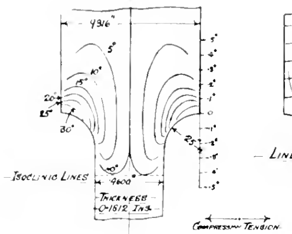


Fig. 5

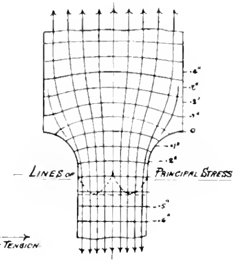


Fig. 6

expression for the greatest stress of the form

$$p_{max} = p \cdot \frac{2c}{c + \frac{2}{3}}$$

where $2\,ca$ is the breadth of the member.

Under the same circumstances the cross stress is given approximately by the formula

$$p_{1r} = 1.42\; p\left(\frac{a^2}{r^2} - \frac{a^4}{r^4}\right)$$

for the larger notches, but for the smallest the coefficient is 1.27.

This notched bar is of interest mainly as a primary form of test piece from which a practical form can be derived by introducing a straight parallel portion, connected by arcs of circles with the ends, and the short tension member now shown, Fig. 1B, is of this form. It is cut from a strip 1 in wide with a length of 1.4 inches between the enlarged ends and a width of ½ in. between them, connected by arcs of ¼-in. radius to the ends.

The color effects indicate at once that only a fraction of the central part is in pure tension, the remaining portions being in a complex state of stress for which the colors indicate maximum values near the join of the straight and curved parts of the contour. Experiment shows that beyond a minimum value the central parallel part has no influence on the stress distribution at the change of section and that the lines of equal inclination of stress which are shown in the polariscope when plane polarized light is employed, clearly mark off the complex stress regions in both parallel parts.

Thus in a specimen cut from a plate of nitro-cellulose 0.1812 in. thick, having enlarged ends 0.9316 in. wide, and connected to a parallel portion 0.4600 in. in width by

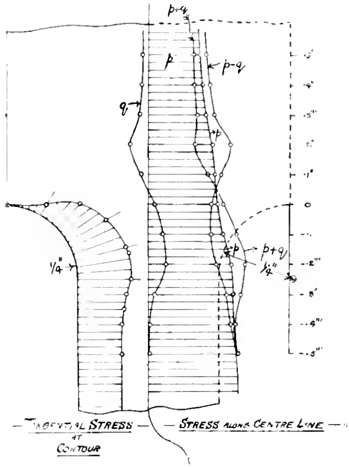


Fig. 7

curves of 0.25-in. radius, the isoclinic lines, Fig. 5, define a region of complex stress extending to nearly ½ in. into the enlarged ends and slightly over 0.4 in. below the shoulders. Above and below these sections approximately uniform stress conditions are obtained as the lines of principal stress, Fig. 6, indicate.

The condition of stress along the central line shows some interesting features as we pass along it from the enlarged ends inwards. At a point sufficiently removed from the discontinuity the stress is uniform, but as Fig. 7 shows, the experimental values of the sum and difference of the principal stresses indicates a gradual rise in this stress accompanied by a cross stress Q which at first is compressive and attains a maximum before the shoulders are reached, then dies away to nothing and becomes a tension with a maximum value below the shoulders, and ultimately vanishes when the region of uniform stress is reached in the narrow portion of the test piece. These changes in the cross stress appear to be due to the inclination of the lines of principal stress and a physical explanation is suggested by considering these latter as flexible lines of force subjected to pulls at their ends. It is then evident that forces are required to maintain the curved forms actually found which tend to compress the material when the lines are concave with respect to the axial lines and to extend it when they are curved. There should on this hypothesis be no cross stress where points of contra-flexure occur, but as these changes do not all take place at the same cross section the effect at the central line is the sum of all the effects across the section, and the zero point of the cross stress Q should occupy a mean position, as it apparently does.

Another feature and the most remarkable one is the stress around the curved contours which has a zero value at the shoulder and is found to rise to a maximum value before it merges into the straight portion. In this case a maximum stress of 1480 pounds per square inch was measured at a point where the tangent to the contour has an inclination of 15 deg. to the central line, although the uniform stress in the gauge length was 1180 pounds per square inch. When the radius at the join was decreased to $\frac{1}{8}$ in., Fig. 1C, the stress rose to 1725 pounds per square inch and a further decrease to $\frac{1}{16}$-in. radius caused a still further rise to 1890 pounds per square inch, corresponding to an increase of stress of nearly 58 per cent as the table shows.

TENSION SPECIMEN .4600 IN. BY .1812 IN. UNDER STRESS OF 1180 LB. PER SQ. IN. WITH ENLARGED ENDS 0.9316 IN. WIDE

Radius of connecting curve (inches)	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$
Maximum stress (lbs. per in.)	1480	1725	1890
Percentage increase of stress	23.4	43.8	57.5

This concentration of stress affords an explanation of the reason why brittle materials often fail near the enlarged ends—an effect often ascribed to imperfect centering, but as the experiments show is more probably due to great local stress which, if the specimen is badly centered in the testing machine, would increase the effect on one side and make a fracture near the ends almost inevitable. In a ductile material the stress distribution changes before fracture is reached and an equalization of stress takes place so that the chance of failure at or near the change of section is somewhat less.

In many cases of cast iron and like materials in tension the broken cross section shows that fracture has taken place just beyond the parallel portion where the stress concentration is shown by optical measurement to be most intense, and this goes to prove that the stress distributions observed below the elastic limit persist in these materials until failure takes place.

TABLE II

Radius of connecting curve ins.	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{1}{16}$	0
Ditto in terms of minimum breadth	.544	.272	.130	0
Maximum distance in inches between the shoulders for which pure tension is not possible	0.82	0.60	0.46	0.42
Ditto in terms of breadth	$1.78b$	$1.30b$	$1.00b$	$0.915b$

The Effective Length of a Test Piece in Pure Tension

It has already been pointed out that the zero isoclinic bands define the region of complex stress, and in the case described this was examined independently by measuring the stress distribution over the whole region, and the results obtained verified this conclusion. It is therefore an easy matter to establish how much of the parallel portion of a test piece is in pure tension.

Thus in the case already cited, where the radius of the connecting arcs was successively diminished from one quarter of an inch to zero with a ratio of breadths of slightly more than two it was found that the penetration of the complex stress distribution into the parallel portion decreased with the radius of curvature, as Table II shows, and therefore, apart from the consideration of increased local stress the test bar with sharpest re-entrant angles has the greatest length in pure tension, although it is less fitted for the purpose required by reason of the high local stress produced. Fig. 1D

For any form of enlarged end it is therefore possible to determine the fractional part of the length k under pure tension for any length of test bar, in terms of the length D between the shoulders and the lesser breadth b. For example, in the present cases with a connecting radius of $\frac{1}{4}$ in.

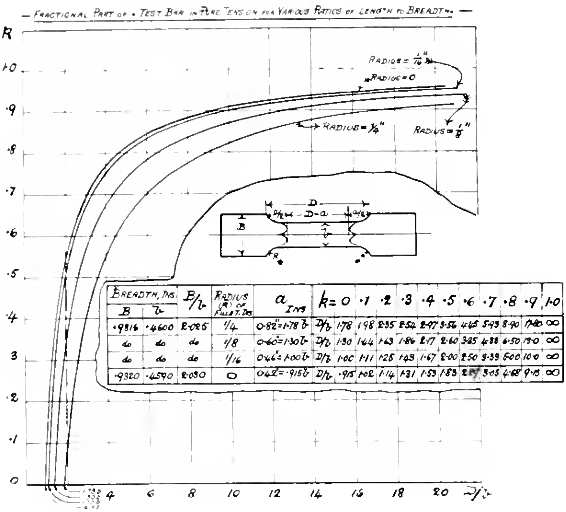
$$k = \frac{D - 1.78b}{D}$$

or

$$D(k-1) = 1.78b$$

a curve of the form xy = constant which continually approaches but never reaches the line k = unity.

The hyperbolic curves showing the general relations of k to D/b are shown in Fig. 8 for the four cases described, and it is clear that similar diagrams may be constructed for any form of plate tension member.



Breadth, Ins. B	Breadth, Ins. b	B/b	Radius (R) of Fillet, Ins	a Ins	k =	0	·1	·2	·3	·4	·5	·6	·7	·8	·9	1·0
·9816	·4600	2·025	1/4	0·82" = 1·78 b	D/b	1·78	1·98	2·35	2·54	2·97	3·56	4·45	5·93	8·90	17·80	∞
do	do	do	1/8	0·60" = 1·30 b	D/b	1·30	1·44	1·63	1·86	2·17	2·60	3·25	4·33	6·50	13·0	∞
do	do	do	1/16	0·46" = 1·00 b	D/b	1·00	1·11	1·25	1·43	1·67	2·00	2·50	3·33	5·00	10·0	∞
·9320	·4590	2·030	0	0·42" = ·915 b	D/b	·915	1·02	1·14	1·31	1·53	1·83	[illegible]	3·05	4·68	9·15	∞

Fig. 8

The British Standard Test Bar for Plates

Apparently the dimensions of the best known British standard test bar were determined by the capacities of the testing machine then available, which made it advisable to secure a cross section of not more than one square inch so that any test piece could be tested to destruction in a fifty-ton machine.

The Engineering Standards Committee therefore adopted a standard gauge length of 8 in. with a parallel part not less than 9 in. long connected by arcs of circles having a radius of one inch to enlarged ends of a width at least half an inch greater than the central portion, this latter being fixed by the condi-

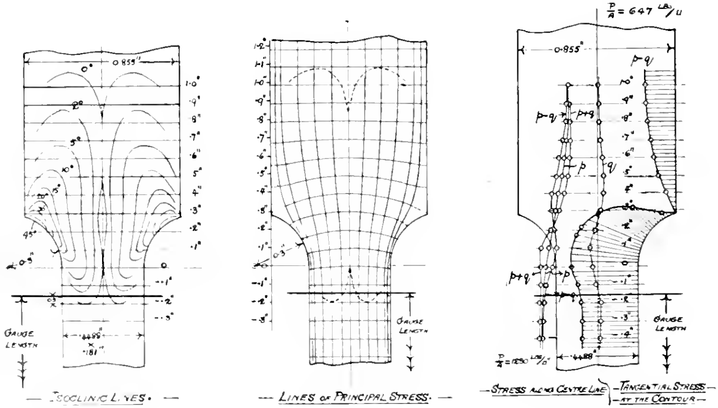


Fig. 9

tion that the total section shall not exceed one square inch.

The most unfavorable case is therefore a narrow width in the gauge length with very wide ends. This standard is so important in British engineering that a very complete experimental analysis was carried out of the stress distribution in a model 3/10 full size having a width 0.4488 in. in the gauge length with a parallel portion corresponding to 9 in., and 0.855 in. at the enlarged ends.

For such a case there is a slight amount of complex stress within the gauge length, as the isoclinic bands and lines of principal stress of Fig. 9 show, but the measurements of the stress distribution along the axis and the contour, as exhibited in Fig. 9, show that the disturbance is insignificant; but just beyond the join of the straight portion with the connecting arcs, where the tangent reaches an angle of about 15 deg. with the axis the stress rises to a maximum of 1470 pounds per square inch when the stress in the gauge length is 1230 pounds per square inch, or nearly 20 per cent more than the mean average value.

Adopting for convenience a zero cross section passing through the centers of the connecting arcs, the principal stresses were determined at points along cross sections 1/10 in. apart in the region of complex stress, and from these observations the normal stress distributions at these sections are shown in Fig. 10, in which the specimen is drawn to different horizontal and vertical scales for convenience of representation. These observations show that in the enlarged ends when approaching the discontinuity the stress is always a maximum along the center line and that the greatest variation takes place across the shoulders, beyond which the stress distribution tends towards a maximum at the sides and finally becomes uniform in the gauge length.

In every case where variations of normal stress occur at a cross section they are accompanied by cross stress and shear, which at some points have considerable intensities. The slightly variable stress distribution in the gauge length was found to disappear when the enlarged ends had a breadth about 13 per cent greater than that of the gauge length, and it was proved that even when the ratio $B/b = 1.905$ it did not occur therein if the parallel part was increased to 9.34 inches. Experiment also showed that there was not much change in the maximum stress at the contour for wide variations in the breadth

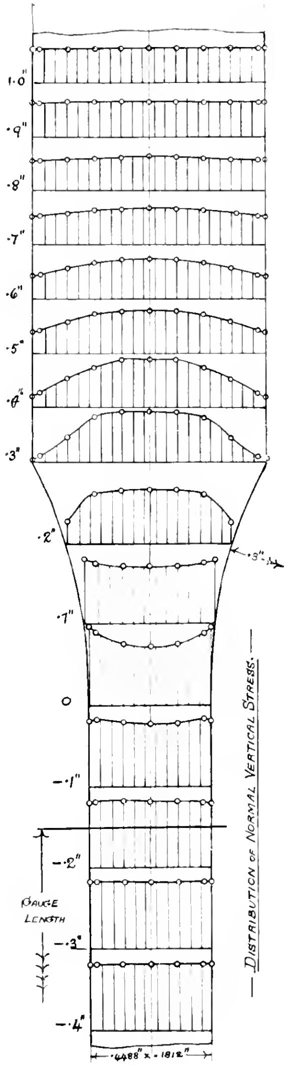


Fig. 10

of the enlarged ends. It is therefore apparent that there is little to criticise in the form, since an increased contour stress seems inevitable for any form, but it would undoubtedly be safer to increase the minimum length of the parallel portion, and thereby avoid all risk of complex stress in the gauge length under any circumstances.

Cylindrical Test Specimens

The experiments do not show what happens for tension members of circular cross section, but some general considerations appear to show that the disturbing effects of the ends are greater in a member formed by a similar contour in the round, for the stress variation is primarily due to the change of section, and in a flat member this is proportional to the width, while in a round bar it is proportional to the square of the width and the disturbing effect is therefore likely to be more widely distributed in the latter case.

It seemed desirable to prove this by direct experiment although it is much more difficult to make observations because a cylindrical rod bends all rays without causing them to come to an exact focus, and a parallel beam is contracted to a narrow band, while the double curvature of the discontinuity disperses the light completely. This difficulty however, was got rid of by enclosing a cylindrical test piece in a flat sided cell, Fig. 11, consisting of two plates of nitrocellulose bored out to nearly fit the specimen, the narrow space between them being filled with a liquid of the same refracture index as the specimen and enclosing plates. The presence of uniformly distributed stress is then shown by bands of color parallel to the contour, and the divergence from parallelism affords a means of detecting the presence of complex stress. In this manner it was shown that the region of complex stress extends somewhat further into the gauge length for a cylindrical rod than for a flat bar of the same contour.

In this connection it is of interest to note that tension tests are often made on short lengths turned from a cylindrical rod. Examples of this kind are furnished by specifications used by the Royal Air Force during the war in which specimens with an area of 1/2 square inch in the reduced part of the section are tested on a gauge length of 2 in. with a parallel part 2 1/4 in. long with curved profiles shaped by arcs of circles

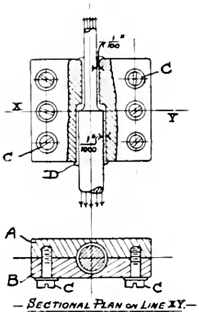


Fig. 11

which in one case is of 7/8 in. radius with enlarged ends 7/8 in. in diameter, and in another has a radius of 1/4 in. and ends as large as possible. Both these forms have been investigated in the flat with the larger width taken as 7/8 in., and it was then shown that in the former the gauge length coincides almost exactly with the extreme length under uniform stress, and that a maximum stress occurs just beyond the parallel portion of 1.11 times the mean stress within the gauge length. In the specimen with 1/4 in. profiles only 7/8 of the gauge length was found to be in pure tension, and the maximum stress increased to 1.17 times that in the gauge length under uniform stress. It is therefore unlikely that either of the corresponding cylindrical forms fulfil the conditions required for a tension test and it has been shown in practice that a considerable proportion of test specimens of hard materials breaks at a section just beyond the parallel part.

(To be continued)

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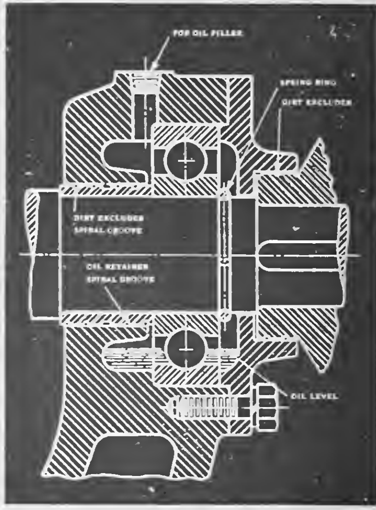

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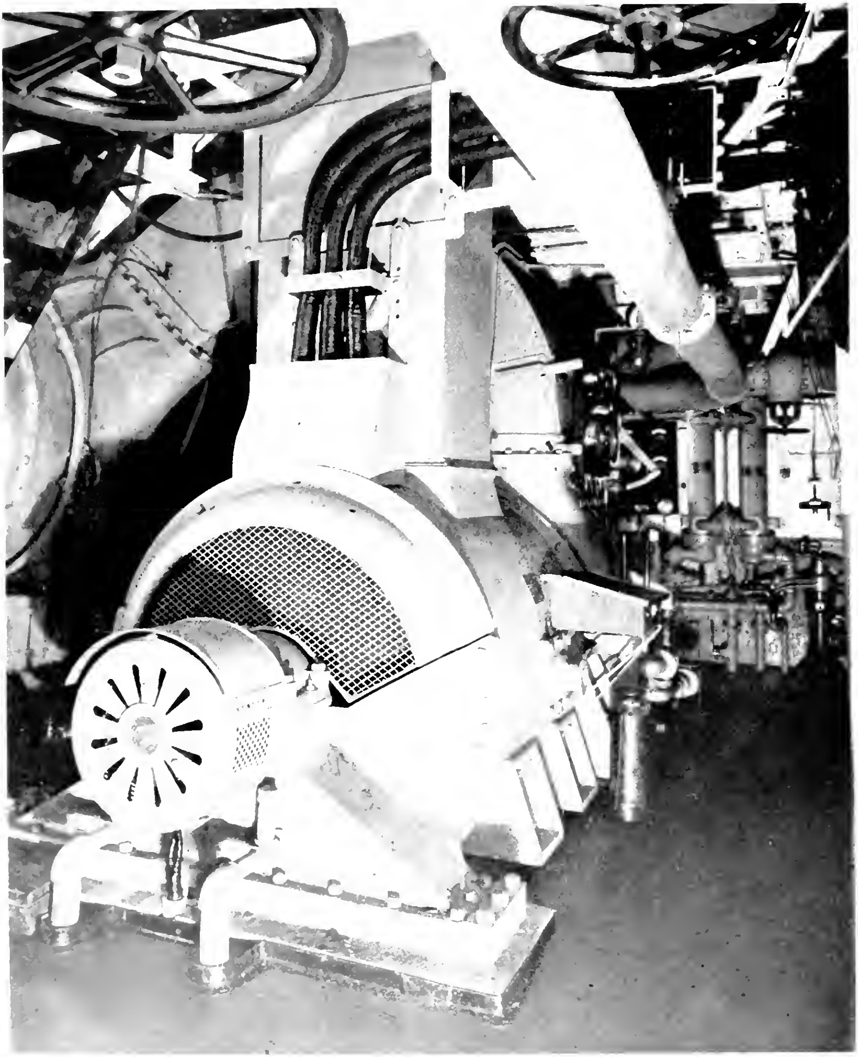


... THE ALL ELECTRIC EXPRESS AND PASSENGER SHIP *CUBA*, SHOWING STARBOARD SIDE OF THE PROPULSION TURBINE GENERATOR

GENERAL ELECTRIC REVIEW

WHY THE GENERAL ELECTRIC COMPANY ADVOCATES ELECTRIC DRIVE OF SHIPS

The beginning of new developments involving elaborate engineering and large constructions are highly undesirable and unprofitable unless they can afford a definite measure of success which will insure repetition orders. The first steps in new lines of manufacture are almost always unprofitable in themselves and many false starts may bring ruin to any manufacturer.

For these reasons it is obvious that, while electric drive may offer a new demand for electrical apparatus, the demand could never form a basis of profitable business unless a definite need was successfully and economically satisfied. These principles were in definite view when the General Electric Company approached the Navy Department years ago with finished designs of electric drive equipments for battleships. The applications which have been made to naval vessels have given a success in exact agreement with predictions and consequently a very large demand has been created in this field.

In the case of merchant ships certain conditions are absent which add to the advantages of this drive in war vessels. Economy at widely varying speeds is not equally valuable and certain matters of location of parts and interchangeability of units in use are less important. In such vessels the reasons for using electrical apparatus instead of mechanical gearing as a speed reducing bond between turbines and propellers is less obvious and should be definitely considered on its merits.

While the Deisel engine for ship work has had a large and very interesting development, it is obvious that in the existing state of our knowledge the use of steam must be considered for most large vessels, and it is also obvious that the high-speed steam turbine has advantages over the engine or the low-speed turbine which must cause the replacement of the latter types if reliable means for the use of the high-speed turbine are available.

The General Electric Company has been the largest producer of geared turbine ship machinery in the world. It has built such machinery for 366 ships aggregating over two million horse power. While a variety of troubles have developed in this work, the average service and durability of this machinery has compared favorably with the results obtained by the best of other manufacturers and the General Electric ships with machinery of certain designs have shown longer service and better results than any other geared turbine vessels.

The Company has carried on extensive experimentation with turbines, gears, and electrical apparatus for ships. These studies have clearly shown that if the conditions of reversing and turbine applications are correctly allowed for, the electric drive gives a transmission efficiency practically equal to that of gears in the best condition; that it affords simple rotation and freedom from mechanical hazards; that it greatly simplifies the turbine and avoids in it dangerous temperature effects; that it affords space saving in most ships and in many cases eliminates long lines of shafting and shaft alleys; and that it is easily repaired without the use of machine shops and affords the most dependable kind of machinery which has ever been used to drive vessels. If such good reasons did not exist, it would be folly for the General Electric Company to try to introduce this method of ship propulsion.

W. L. R. Emmet.

A NEW ERA FOR ELECTRICITY IN THE MERCHANT MARINE

The remarkable progress during the last thirty years in applying electricity to the operation of machinery in many different branches of industry makes all the more conspicuous the lack of extensive installations in the merchant marine. With a few exceptions, the electric equipments of cargo ships consist chiefly of generating sets and lights. Many large passenger liners built in Great Britain or Germany have had rather extensive electric equipments, but even in many of these the deck winches and anchor windlass are operated by steam.

This failure to utilize electricity for power applications in the past may have been a result of the conservatism of ship owners and shipbuilders, due to a belief in the inability of electric apparatus to meet the service conditions on shipboard or to a fear that the working force on ship or dock might not readily become accustomed to the operation of such machinery, or it may have been due to the lack of sufficient interest and enthusiasm on the part of electrical manufacturers; but the advent of the motor ship has introduced a new factor into the situation that is expected to bring about a very large use of electrically operated auxiliaries on steam ships.

The great saving in fuel accomplished by using electric generators driven by internal combustion engines for operating electric auxiliaries, as compared with steam auxiliaries supplied by a special boiler for that purpose, has led recently to a considerable use of electric auxiliaries on motor ships. The experience thus obtained will lead to greater confidence in the economy, reliability, and convenience of installation and operation of this class of machinery; and once this confidence is obtained it cannot be doubted that steamship owners will be favorably impressed.

The superiority of electric apparatus is well shown by its very extensive use in late years by the U.S. Navy on war vessels. During the Spanish war only two turrets were trained by electric motors, in addition to which there were but a few small motors of seven horse power and less for operating ammunition hoists for eight-inch and smaller guns and also a few small blower motors. From 1898, when the large electric installations on battleships were begun, the use of electricity for this purpose has extended to nearly all the auxiliaries outside the engine and fire rooms, including steering gear, anchor windlass, warping capstan, deck winches, boat cranes, ventilating blowers, pumps, turret turning, gun elevating, gun rammers, ammunition hoists, galley and laundry machinery. On the latest eleven battleships and six battle cruisers the propelling equipments are electric, as are part of the turbine room auxiliaries. If twenty-five years of continuous experience with electrical apparatus on shipboard has led the Navy Department to adopt it so extensively, it may surely be expected that its use on passenger and cargo vessels will give entirely satisfactory results.

There is one incidental advantage in the electric operation of auxiliaries and of propelling machinery that should not be overlooked, and that is the ease of making power measurements. Thus to the natural economy of electric operation is added the refinement of further improvement of economy by a study of the power consumption of various kinds of equipment with a view to selecting the most efficient apparatus and methods of operation.

It has been considered by some that the cost of electric equipment is considerably more than that of steam equipment. While certain individual pieces of machinery, such as deck winches, cost more when provided with electric motors and control than when provided with steam engines, the cost of the installation as a whole, including electric cables in place of steam pipes, and also including the labor of installation, is not excessive when considered in connection with its advantages of operation and maintenance.

The authors of the articles in this issue are thoroughly familiar with service conditions on shipboard and have made a careful study of the characteristics required of the apparatus, and it is believed that their statements will promote a more favorable consideration of the use of electricity on shipboard, leading to an extensive electrification of vessels comparable to that already existing in factories.

Maxwell W. Day.

Our American Merchant Marine

By Rear Admiral W. S. Benson

Chairman, United States Shipping Board

Our shipbuilding is in rivalry with no one. We were content to see our commerce carried in the bottoms of other nations. It was not until urged by our allies to engage in shipbuilding on a stupendous scale that we attempted to rehabilitate our fast diminishing fleet. A world emergency—the civilization of the world was at stake and we were told that ships and more ships were the crying need. They that went out for ships we answered and the noble response of our citizens who bought Liberty Bonds to finance the building of these ships aroused the admiration of the world. The records of our shipbuilders stirred the imagination of all. It was real teamwork and history in the making. Our workmen broke world records in ship construction and riveting rivalry speeded up shipbuilding. America applauded these efforts. Then came the armistice. A new set of problems was before us.

It took courage to spend large sums of money in this effort, and Edward N. Hurley showed how big a man he was by the courageous way in which he met the problems before him, first in the construction of ships and then in handling the situation when a sudden cessation of hostilities completely upset the huge war machinery set up under his direction. Mr. Hurley was equally as brave and farsighted when he cut down our construction program to a point where we saved more than $600,000,000 by the cancellations he effected. It was no easy task and men of large affairs know what problems must have confronted the Shipping Board when it saw the need of shutting off many shipbuilding activities. Problems of reconstruction; the need of employing our returning soldiers; the fear of sudden stoppage of work precipitating undue injury upon patriotic men· all had to be considered.

But that is now history. It is what we have before us today that is of most interest and so I shall deal with that. The United States Shipping Board came into existence several months before we entered the World War. Its real purpose was to be a regulatory body of shipping, with vast powers that could be utilized to build up our merchant shipping. The Shipping Board had hardly assumed an organized form when the United States was drawn into war. Then we plunged into a record breaking ship construction program, which is now near completion. The ships which we built during the war played a winning part, carrying our products to the men at the fighting front. It should not be forgotten that as a result of our merchant marine and what we were able to whip into shape between the declaration of war and the time when our men were ready for hostilities 95 per cent of their supplies including munitions were carried overseas in American bottoms. Approximately 45 per cent of our fighting men went over in American bottoms. That is, about a million men sailed overseas in our ships.

I believe that we must develop a better motive power for our ships. My own thought is this: We know the effectiveness of the Diesel engine and its economy, and my present intention is to try to develop the same principle in the electric generator and to use the electric power as the motive power for driving the ships; in other words, the electric drive. We have demonstrated in our battleships that the electric drive is much more economical than the ordinary turbine engine. It was my privilege to combat the opposition to turbine drive and to make electric drive permanent in our battleships.

The electric drive is more economical than the ordinary turbine engine, and we all know that the Diesel oil engine is much more economical than the ordinary method of driving ships. I am using every effort that I can to develop the Diesel principle in connection with the electric generator, with the purpose of using the electric current, which is no longer an experiment for driving ships.

Practical ship operators will realize the tremendous waste of power, weight, room, and everything, in the various auxiliaries aboard our ships. We must do away with them. We must use something, and I believe the electric power is the thing that will do it, for all of our auxiliaries aboard ship; all of these little things must be looked after. We must save every pound of coal, every gallon of fuel-oil, that we possibly can; and when I say coal I say it with a great deal of regret, because our competitors will try to persuade us that we must go back to coal burning, that we cannot get oil in all parts of the world, or that it doesn't pay, or something of that kind. If we ever give up fuel-oil in these modern times, unless we can get something better, we might as well take to the woods and cut wood for our fuel. We can't cope with foreign competitors on any other basis.

I feel this thing most seriously, and I mention some of these things because this is not a ship owner's, nor a shipbuilder's, nor a seafaring proposition; it is an American proposition, and it appeals to every American citizen.

control and use of the radio service by the government under the Navy, which has proven so effective and so useful to the commercial interests, not only during the war, but since the armistice.

Those who worry most about our entrance into ocean commerce must be our cousins overseas—the British. For many centuries the mistress of the seas, she has carried the message of commercial advancement. But it is essential that the world should understand that we, who fully appreciate the

TABLE I

	TOTAL			EXPORTS			IMPORTS		
	Relative Rank	Tonnage	Percentage of Total	Relative Rank	Tonnage	Percentage of Total	Relative Rank	Tonnage	Percentage of Total
New York	1	5,750,702	27.9	1	3,099,815	23.2	1	2,650,887	36.6
Baltimore	2	2,065,465	10.0	2	1,608,179	12.0	4	457,286	6.3
Philadelphia	3	2,061,268	10.0	4	1,304,886	9.8	2	756,382	10.5
New Orleans	4	1,560,729	7.6	6	867,934	6.5	3	692,795	9.6
Norfolk	5	1,470,349	7.1	3	1,371,607	10.3	13	98,472	1.4
San Francisco	6	1,042,811	5.1	7	606,300	4.5	5	436,511	6.0
Newport News	7	972,479	4.7	5	953,839	7.1	22	18,910	.3
Savannah	8	732,807	3.6	10	400,655	3.0	8	332,152	4.6
Seattle	9	679,558	3.3	9	536,345	4.0	10	143,213	2.0
Boston	10	677,839	3.3	12	286,011	2.0	7	391,828	5.4
Galveston	11	659,655	3.2	8	555,287	4.2	11	104,368	1.4
Port Arthur	12	558,612	2.7	14	148,466	1.1	6	410,146	5.7
Mobile	13	409,768	2.0	11	341,353	2.6	15	68,415	.9
Charleston	14	344,501	1.7	15	148,296	1.1	9	196,205	2.7
Portland, Ore	15	262,243	1.3	13	248,676	1.9	25	13,567	.2
Jacksonville	16	149,209	.72	16	131,509	1.0	24	17,700	.2
Portland, Me.	17	145,900	.71	18	97,481	.7	17	48,419	.7
Perth Amboy	18	123,381	.60	30	19,363	.1	12	104,018	1.4
Wilmington, N.C.	19	116,460	.57	29	23,495	.2	14	92,965	1.3
Los Angeles	20	115,106	.56	19	96,677	.7	23	18,429	.3
Pensacola	21	80,678	.40	20	52,923	.4	18	27,755	.4
Tacoma	22	30,207	.15	36	7,627	.06	21	22,580	.3
Tampa	23	29,403	.14	28	25,909	.2	28	3,494	.05
San Pedro	24	16,071	.08	32	13,296	.1	29	2,775	.04
Houston	25	15,248	.07	33	13,168	.1	30	2,080	.03
Key West	26	8,855	.04	44	705	.01	26	8,150	.1
Total		20,079,574	97+	...	12,959,802	97+		7,119,772	98+

It is necessary for us to have a merchant marine in which we can carry our surplus products to foreign countries. We need it in our national defense. We need it in every phase of our life, and now, at the close of my professional career, and accepting this position as Chairman of the United States Shipping Board, I appeal to every American citizen to give us earnest, sympathetic and constructive support.

Further[illegible] in view of the international [illegible] throughout the war, [illegible] should be given to the service rendered by other nations, are now ship independent in the development of our ocean carrying trade. We mean to play our part in manly American fashion, and have done so from the start.

Gladly I would and do pledge myself to help see that not only my own but other governments be brought to a point where they fully agree to retire absolutely from ocean carriage which could only mean uneven competition with the private owner. We are endeavoring to do this as quickly as possible and the law demands it.

TABLE II

	EXPORTS		IMPORTS		EXPORTS AND IMPORTS	
	Tonnage	Percentage of Total	Tonnage	Percentage of Total	Tonnage	Percentage of Total
1919						
July	741,943	5.55	448,848	6.20	1,190,791	5.78
August	1,621,867	12.12	437,294	6.04	2,059,161	9.99
September	1,448,528	10.83	476,146	6.58	1,924,674	9.34
October	1,080,135	8.07	714,118	9.87	1,794,253	8.70
November	1,078,404	8.06	435,079	6.01	1,513,483	7.34
December	1,000,099	7.47	503,881	6.96	1,503,980	7.30
1920						
January	951,986	7.11	403,045	5.57	1,355,031	6.57
February	883,925	6.61	677,667	9.37	1,561,592	7.57
March	984,514	7.36	695,769	9.62	1,680,283	8.15
April	1,311,241	9.80	881,825	12.19	2,193,066	10.64
May	1,162,551	8.69	707,889	9.78	1,870,440	9.07
June	1,114,041	8.33	854,607	11.81	1,968,648	9.55
Total	13,379,234	100	7,236,168	100	20,615,402	100

The magnitude of our effort in world shipping may seem to spell disaster to other nations. But it should not. We are only making up for the submarine. By force of world emergencies we have had to replace the enemy whose proud position in maritime fields was wrested from her by the splendid work of our allies with whom we fought during the most deadly part of the war.

Figures are uninteresting as a rule but I must submit them in order to give a fair analytical presentation of conditions. An analysis of Shipping Board activities in export and import trade for the fiscal year ending June 30, 1920, will be helpful.

A résumé of the activities of Shipping Board vessels shows that during the fiscal year these vessels carried exports of 13,379,234 tons and imports of 7,236,168 tons, a total of 20,615,402 tons, through forty-nine United States ports. In this connection it is noted that 24 per cent (1,720,733 tons) of the imports consisted of crude petroleum. Exports were forwarded from forty-four ports and imports were received at thirty-one ports. Twenty-six of these ports handled over 97 per cent (20,079,574 tons: exports 12,959,802 tons, imports 7,119,772 tons) of the entire tonnage moved. Table I shows these twenty-six ports arranged in order according to total tonnage handled by each. Relative rank by volume of exports and imports, as well as the percentage of the total tonnage handled through each port, is also indicated.

As of particular interest it is noted that of our total foreign trade during the year, 71,586,250 tons, 57 per cent (40,463,397 tons) was carried by American vessels, 29 per cent by Shipping Board and 28 per cent by independents. Table III shows the relation of Shipping Board and other American carriers to the entire foreign commerce of the United States during the fiscal year ended June 30, 1920.

The total documented sea-going merchant marine of the United States (500 gross tons

TABLE III

	AMERICAN								FOREIGN		TOTAL
	U.S.S.B.			Independent			Total				
	Tons	Per Cent of Amer.	Per Cent of Total	Tons	Per Cent of Amer.	Per Cent of Total	Tons	Per Cent of Total	Tons	Per Cent of Total	Tons
Exports	13379234	63	30	7942552	37	17	21321786	47	23793933	53	45115719
Imports	7236168	38	27	11905443	62	45	19141611	72	7328920	28	26470531
Total	20615402	51	29	19847995	49	28	40463397	57	31122853	43	71586250

and over) at October 1, 1920 consisted of 3482 vessels of 11,708,342 gross tons or approximately 17,562,513 deadweight tons.

Of this total the Shipping Board now owns 1627 vessels of 6,862,518 gross tons, equivalent to 10,293,308 deadweight tons. Of this total owned by the Shipping Board 693 vessels of 3,036,065 deadweight tons are vessels of less than 5000 deadweight tons each.

Vessels between 5000 and 6000 deadweight tons number 147 or 771,731 deadweight tons.

The tonnage of active vessels at present controlled by the Shipping Board exclusive of the vessels operated by the Army and Navy and under Bareboat and Time Charter are distributed in the various trades as follows:

38 per cent in Northern European
9 per cent " Southern European
4 per cent " African
17 per cent " Trans-Pacific
15 per cent " South American
9 per cent " West Indies and Caribbean
6 per cent " Domestic Service
2 per cent " Operating between foreign ports

Of the steel vessels owned by the Shipping Board engaged in these services 589 are operating from North Atlantic ports, 89 from South Atlantic ports, 229 from Gulf ports, 132 from Pacific ports, 89 are employed in coastwise service, 53 are operating between foreign ports, 113 are at present unallocated to any designated berth liner service. These latter virtually constitute the tramp service of the fleet.

Of the total operating on the North Atlantic District 274 vessels are operating from the Port of New York, 102 from Norfolk, 90 from Baltimore, 70 from Philadelphia, 23 from Boston and 1 from Portland, Maine.

The total deadweight operating from North Atlantic ports is 3,991,504. Of the total tonnage operating in berth liner service 54 per cent of the deadweight tonnage is operating from the Atlantic ports.

The total tonnage operated by the United States Shipping Board excluding vessels operated by the Army and Navy at October 1, 1920, numbered 1611 vessels or a deadweight tonnage of 10,150,759. Sixteen vessels were operated by the Army and Navy.

Of the 1627 vessels owned and controlled by the Shipping Board on October 1, 1920, 1504 were cargo vessels, 27 were cargo and passenger vessels, 76 were tankers, 15 refrigerators, and 5 transports.

The cargo and passenger vessels include two chartered from Peru on which the Shipping Board has an optional agreement of purchase.

Included in the total number of vessels owned and controlled at October 1, 1920, are 284 wood and composite vessels, and 5 concrete vessels.

At the close of September, 1920, 60 of these wood vessels were in active service and 224 were in charge of managing caretakers and withdrawn from operation.

And now we come to the manning of our ships. At the time we entered the World War there was not only a shortage of American ocean tonnage but of men to man the bottoms embraced in the ship construction program. To meet this condition, the Board has to date trained through its Recruiting Service over 14,000 officers and 33,000 men below the grade of officer for the Merchant Marine. During the fiscal year ending June 30, 1920, the Sea Service Bureau placed on American vessels a total of 160,861 officers and men of which number 65 7/10 per cent were Americans. When the Shipping Board through its agencies first began placing men on ships in 1917, at the Port of New York, which is used as an example because it is the most represented, 90 per cent of the crews placed on American vessels were aliens.

For the past twelve months 37,271 officers and men were placed on American ships by the New York office of the Sea Service Bureau. Of that number 60 per cent were Americans; the percentage of Americans in the Deck and Steward's Department is lowered by the percentage of aliens in the fireroom, there being more aliens serving in that department than any other on board ship. Of this number 9318 were able seamen; 4937 or about 53 per cent of that total were Americans, while 4881 were foreigners. A total of 2968 ordinary seamen were placed in sea service, of this total 2641 or nearly 90 per cent were Americans. The ordinary seamen of today are the able seamen and officers of tomorrow. In addition to its other activities, the Recruiting Service of the Shipping Board has trained several hundred skilled licensed engineers in the operation and up-keep of marine turbines; twenty-three especially qualified men have been trained on the electric drives. We are going forward with the work of developing and raising the standard of the personnel of our ships.

The value of a Merchant Marine as an asset to this Nation is enhanced by the fullest employment of Americans in that service. During the war it was necessary to give employment in the Merchant Marine to nationals of the countries allied with the United States. Most valuable service was rendered by these nationals and theirs was a great contribution toward the winning of the war.

The time has now come when our American Merchant Marine should be put upon a peace footing and every effort is being made to increase the proportion of American citizens in its employment.

Activities of Merchant Marine and Fisheries Committee of the House of Representatives

By Hon. Frank Crowther

Member of the Committee

The Merchant Marine Act of 1920 is the result of a number of exhaustive hearings and investigations held and made by the Merchant Marine and Fisheries Committee, covering a period of nearly four months. The Committee found that in order to establish regularity in the future conduct of the numerous different shipping activities operated either by order of the President through emergency legislation or by the original Shipping Act, it would be necessary to concentrate all of these operations under one authority, repealing such legislation rendered unnecessary by the ending of the war and providing new legislation for the operation and handling of the property.

With this end in view the bill (H.R.10378) has for effect, first, the repealing of the various bills containing legislation in connection with the upbuilding of the merchant marine, together with the bills containing the unusual powers granted to the President which were essential for successful operation during the war. It also transfers all the power necessary for its liquidation, construction, or operation to the Shipping Board, fixing the scope of the Shipping Board's powers so that it can absorb all these activities.

At the beginning of the World War less than 10 per cent of our foreign trade was being carried in American ships. On April 27, 1920, the United States owned approximately 2000 merchant vessels, of which 1149 were of a desirable type of steel vessel aggregating in round numbers 7,000,000 tons.

The Committee realized that the operation of such a gigantic fleet constituted the greatest commercial enterprise in the world. Our fleet represented an investment per registered ton far greater than a like investment in the vessels of any other nation. The costs of operation, in compliance with the existing Shipping Act, were far greater than for other nations. It was therefore necessary to frame such legislation as would provide every possible advantage for vessels of the United States when owned by American citizens, in order to in a measure offset these stated and other adverse conditions.

The various branches of the executive force of the Shipping Board appeared before the Committee and were most courteous and painstaking in supplying us with a fund of valuable information.

The Committee sought information and advice from every possible source, and the ordinary seamen who appeared in opposition to one particular measure were given as much consideration as though they had been the owners.

The various sub-committees gave careful consideration to the problems of load line, registry, ship mortgages, and marine insurance; and the result of their labors is manifest in the sections of the bill relating thereto.

The Committee realized that possession of a large tonnage did not constitute a permanent merchant marine. Steamship lines must be established, and regular, certain, and permanent service secured. This will lead to the establishment of commercial agencies and the creation of business facilities which we do not now have but are necessary to success.

We need a Merchant Marine not only for our commerical growth, but for the nation's defense in time of war and the stability of domestic industry in time of peace.

As the activities of the committee are voluminously reported in many hundred pages of hearings, I have tried to describe but a few of the salient features of our task, and thus comply with the editor's request as to brevity.

The American Bureau of Shipping

By Stevenson Taylor

President, American Bureau of Shipping

In all discussions anent the rehabilitation of our long neglected American merchant marine, there has been an apparent unanimity of thought that one of the essentials of this much desired national movement is an efficient and firmly established classification society. This fixed determination on the part of the leading proponents of the revivification of American shipping crystallized into action early in 1916, by a definite program of refinancing and breathing the breath of life into the then existing but somewhat somnolent American Bureau of Shipping. It possessed a broad charter from the State of New York, and had been in more or less successful operation since 1862, its history and vicissitudes during that long period being but reflections of the changing status of our national merchant marine.

Gigantic have been our shipbuilding strides since 1916, and today we are the proud possessor of a fleet of merchantmen comparing favorably and only secondarily in size to that of Great Britain which for nearly a century past has led all the nations of the earth in ocean commerce. The expansion of our American classification society, despite many discouraging circumstances, has been proportionately as great to keep pace with the needs of our fleet. From an organization in 1916 having but two offices and a dozen or so employees, it is today in a firm financial condition and its branch offices cover all the principal seaports of the United States. All places where ships are built or where ship material is manufactured are looked after by its surveying forces. In addition, by its alliances with the British Corporation, the Registro Navale Italiano, and the Imperial Japanese Marine Corporation, it has representatives in every port throughout the world where American ships call in the extension of our foreign commerce. At such ports as Hamburg, Antwerp, Havre, Bordeaux, Shanghai, Rio Janeiro and Havana there have already been established exclusive surveyors for the American Bureau, and many more will be located shortly in order that our [illegible] may have the services of skilled [illegible] surveyors where they are most [illegible].

The rules of the American Bureau of Shipping are essentially the same as those adopted by the British Corporation. This code is the embodiment of the best practices in ship construction, and was prepared by the best technical talent obtainable in the shipbuilding industry. To keep pace with the rapid advancement in the art of building internal combustion engines, the Bureau's technical staff is at present engaged in the formulation of a new set of regulations for the construction of this most economical method of ship propulsion. In the preparation of these rules, the Bureau has consulted with the best technical talent from the various American manufacturers of this type of engine.

The rules for the construction of wooden ships have recently been revised along the same lines of procedure, so that when they are promulgated they will epitomize the best practice in the world for that particular type of vessel. Although steel has practically replaced wood for ship construction, there will be in this country, especially, a number of wooden craft constructed for particular trades for a number of years yet to come.

In order to cover all classes of floating property in which marine underwriters are interested, the Bureau will shortly undertake the codification of special rules to govern the construction of certain types of river and harbor steamers, barges, car floats, etc., which thus far have not received the benefit of special classification by any society.

It is also contemplated that at no very distant date, rules will be drawn up to cover the construction of motor boats, of which there are thousands in American waters and which at this time are insured without recourse to information as to construction and upkeep which should be furnished by a classification society.

The American Bureau of Shipping is now, by act of Congress, recognized as the official classification society of our national government. It is the ambition of its Board of Managers to obtain the whole-hearted support of all citizens interested in American shipping, so that it will be in fact a truly national society for the classification of all types of vessels that ply our waters and carry our flag on the seven seas.

Activities of the National Marine League of the U. S. A.

By Felix Riesenberg

Editor of *The National Marine*

Back in 1913 a group of gentlemen met in Washington, D. C., under the leadership of Mr. P. H. W. Ross and incorporated the National Marine League of the U. S. A. The third provision of their charter reads as follows:

"The particular business and objects of the corporation are to solicit subscriptions and receive gifts from the public and by means of educational propaganda to arouse the people throughout the United States (and especially those living in the interior) to a full understanding of the necessity of re-establishing an American overseas commercial marine, particularly for the expansion of our commerce with South America and Asia through the Panama Canal.

"To formulate and promulgate measures for this purpose, from the standpoint of a broad national policy and development, avoiding that of any special interest.

"To promote full recognition of the paramount need of providing world-wide export outlets for the products of our manufacturing industries, in the interest of steady and profitable employment of both labor and capital.

"To establish and maintain in various parts of our country and to encourage the establishment and maintenance by others of Marine Hospitals, Marine Schools and Marine Memorial Halls or other Institutions having for their object the inspiration and education of the youth of our Republic in the maritime interests of this country and their development and also the care and reward of those who have served on the High Seas and are deserving of such reward."

At the time when this program was solemnly adopted, Kaiser Wilhelm II sat upon the throne of the German Empire and the harbors of America were crowded by mighty liners flying the red, white and black flag of the Prussian state. Then too, millions of our people regarded the sea as the special highway of foreigners, having, through several generations of neglect, come to forget the great days when the Stars and Stripes circled the world on the finest and fastest craft afloat, all of them manned by Yankee sailors.

The word "propaganda" had no sinister meaning in those days and it was used honestly by the founders of the League. We were an unsuspecting people, and many Americans were then firm in their belief that not one dollar of public money should ever be paid out in the form of subsidies to encourage the shipbuilders and ship operators of America. We were content, however, to pay many millions of dollars each year to the sailor nations of the world. A great deal of foreign money (first conveniently collected from Americans) was spent by active gentlemen who did much to further this strong feeling on the part of shore staying Americans. The United States was the happy hunting ground for the foreign propagandist.

In the years before the World War while America stood like a fat cow in her stall, countless millions were milked away in the form of shipping, banking, brokerage and insurance profits; and the greatest nations of the world sent their ships to our ports to carry away our cargoes at their own price.

This is not a history of the World War though it would almost be that if the full story of the National Marine League's activities were told. The beginning of the war found the League functioning in a modest way through the help of a small group of far-sighted and patriotic men such as J. Pierpont Morgan, August Belmont, and Alexander Hemphill, the two latter gentlemen now active as trustees of the League.

In the midst of the war, while America stood on the brink of the conflict and her people gradually awoke to the need for ships —American ships, built, owned, and manned by Americans—the League continued its work with added vigor. Thousands of speeches were made and hundreds of thousands of pamphlets and leaflets were distributed. The League became the great forum through which the chairman of the United States Shipping Board made public his annual messages. Chairman Hurley, on two such occasions, stirred the country to patriotic fervor by his announcement of the astounding total of the country's maritime achievement. Chairman Benson, following chairman Payne, has used the great gatherings of the League to pronounce his most important messages. Always the League has stood at the forefront of patriotic effort for the welfare of our shipping and the advancement of every American interest upon the sea.

The list of the League's contributions toward the great awakening that we now enjoy is of an enlightening character. *Ships and The Middle West* was reprinted by the Boston *Transcript* in March, 1912, being a reprint from the London *Fortnightly Review* in which Mr. Ross, then on a tour of investigation in Europe, sounded the need for an American Merchant Marine.

In 1911 *The Western Gate* was published in New York, by Dodd, Mead and Co., and this book combined with the report of Mr. Ross' observations abroad gave hope to the group of men who were his followers that an

WE'VE TURNED THE CORNER—SHALL WE SLIP BACK, OR—"*FULL STEAM AHEAD?*"

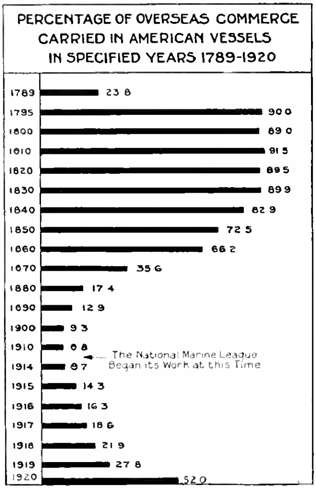


Fig. 1. Reproduction of a Chart published and widely distributed by the National Marine League

American Merchant Marine might yet come into being if the people could be aroused.

As Dixie Sees It, *Why?* and a number of other pamphlets were then widely distributed. These were followed by *The Partnership of the People in Foreign Ventures*, and *America's Maritime Destiny*, an address delivered by Mr. Ross before the Detroit Board of Commerce, Jan. 18, 1916. *A Brief on the Bearing of the War Upon Commercial Treaties* (1916), and *A Brief on the Shipping Bill*, also of 1916, were both written by the late Carman F. Randolph of the New York Bar, especially retained by the League to prepare these works. *The Merchant Marine in Its Relation to the Navy and Preparedness*, was read by Mr. Ross before the National Security Congress at Washington, in January, 1916.

Many pamphlets then followed in quick succession and were widely read and commented upon in the press throughout the land. Perhaps the greatest good was accomplished by the wide distribution of an address made by Mr. Ross, before the Illinois Manufacturers Association in Chicago, on Jan. 9, 1917. This paper, *Sea Lords of the Middle West*, is still being quoted by widely scattered publications throughout the vast agricultural section of the United States. It was commented upon by the press abroad and served notice upon the world that America, in spilling her blood and treasure as we were bound to do, would also fight for her own right in the great commercial movements of the world. It carried the message that the backbone of this demand must come from the Middle West among the farmers and manufacturers of the Mississippi Valley.

The League is ever in the forefront in seeking light and spreading it where it will do the most good. *We Have the Ships—Give Us the Men*, expressed that spirit and foresight so essential to success. In furtherance of this aim to officer and man our ships by Americans, the League published its *Model Nautical Training Act*, based upon the successful act of New York State, and stood firmly behind the system of State and Federal co-operation in the training of merchant service officers for the deck and engine room. The League knew that only trained Americans would be able to hold and keep in hand the great fleet of ships then on the ways.

No effort was spared to spread the gospel of service and good will and effective cooperation. *How to Make Seafaring a Permanently Attractive Calling* was prepared by August Belmont, the chairman of the Board of Trustees of the League, and gave to the public the mature deliberations of a banker of internatonal reputation. Major Belmont stands firmly behind the policy of governmental insurance for the seamen of our commercial fleet.

Mr. Carman F. Randolph then prepared his famous paper on our navigation laws. This appeared during the long deliberations preceding the passage of the Jones bill, otherwise known as the Merchant Marine Act of 1920. This paper, *A Brief in Advocacy of an Improved Legal Regime for the American Merchant Marine*, was widely read and studied by the many men who were active in framing the Act of 1920.

Constantly, without fear or favor, the League has stood for what is best for the American Merchant Marine. It has made friends and foes; but it has never taken sides in the many disputes that have arisen within our ranks. It is not for ship operators as against seamen, or shipbuilders. It is not for either of these as against the others.

The League has expended its energies for the common good in the great effort to bring something out of nothing, to build up instead of tear down, to give hope and interest to the many who have grown up in utter ignorance of the vital meaning of ships and shipping to a free people.

Early in the fall of 1919 the League launched its First National Marine Exposition, which was arranged to take place at the Grand Central Palace during the week of April 12 to 17. This huge undertaking was a severe strain upon the resources of the League. For months in advance the public in general and shipping people, who at first held aloof, were educated in the advantage, to all, of a get-together exhibition for the information of the people and for the mutual help and encouragement that such an enterprise was bound to bring with it.

The exposition was inaugurated by National Marine Week, during which time a series of celebrations was staged, not only in New York but in other ports. The Secretary of Commerce, Joshua W. Alexander, presided at the inaugural luncheon on board the U. S. Shipping Board Steamer *West Alseck*, where a notable gathering of prominent shipping men were entertained as the guests of the Oriental Navigation Company.

On the evening of April 13, the annual banquet of the League brought together over a thousand members and their friends at the Hotel Commodore; Admiral Benson then delivered a striking address.

During the whole week of the exposition great crowds came in increasing numbers until, during the last few days, it was hard to get into the Palace, although at this time the eastern states were in the midst of the railroad strike and few out-of-town people came to the exhibit. The attendance was only exceeded by the automobile show totals, and on the latter days it passed the figures for this great exhibit, showing a real popular interest in ships and the sea. The year 1920 saw the success of the National Marine Exposition in Chicago in October; 1921 brings in the second great National Marine Exposition in New York.

The League now has over ten thousand members and publishes a monthly magazine, *The National Marine*, devoted to a popular exposition of all phases of shipping.

The officers and trustees of the National Marine League are: P. H. W. Ross, President; George W. Harper, Jr., Vice-president; Trustees, August Belmont, Chairman, Edward J. Berwind, Oscar L. Gubelman, George W. Harper, Jr., Alexander J. Hemphill, William Fellowes Morgan, Frank C. Munson, P. H. W. Ross, Guy E. Tripp, and Jesse R. Lovejoy.

Back of these stand the members of the National Committee who are publicly pledged to support the League in its work for the growth and permanent welfare of the American Merchant Marine. These gentlemen believe that the Merchant Marine is a source of national strength and security to our country. They believe that we, as Americans, are fully entitled to our just share of the ocean-borne commerce of the world.

Nautical Schoolships

TRAINING OFFICERS FOR U. S. MERCHANT MARINE

By J. S. Baylis

Superintendent, N. Y. State Nautical School

In 1874 Congress passed an Act to promote nautical education by authorizing the Secretary of the Navy to furnish, upon application in writing from the governor of a state, a suitable vessel of the Navy with all her apparel, charts, and instruments of navigation. The following ports are the only ones mentioned in this Act: Boston, Philadelphia, New York, Seattle, San Francisco, Baltimore, Detroit, Saginaw (Michigan), Norfolk, and Corpus Christi. To correct an erroneous impression that schoolships are reformatories, this act explicitly provided that no person shall be sentenced to or be received at such schools as punishment or commutation of punishment for crime.

The following year, 1875, New York State took advantage of the Act and organized the New York Nautical School, its work being carried out on the old full-rigged sloop of war *St. Marys* which was turned over by the Navy for the schoolship and served as such until 1907 when it was replaced by the U.S.S. Gunboat *Newport*. The *St. Marys*, while in this service of its country and state for over thirty years, trained over 2,700 young men for a seafaring career.

A few years later, 1891, Massachusetts passed a law authorizing a nautical training school and in 1892 the U.S.S. *Enterprise* was turned over to the State for a schoolship.

In 1889, Pennsylvania passed a law authorizing a nautical school and received the old full-rigged sloop of war *Saratoga*.

These old schoolships were of international fame, and supplied hundreds of officers for our merchant marine, many of whom are now marine superintendents, masters of our largest ships, or filling other positions of great responsibility. These schools in addition to supplying officers for our merchant marine have furnished many to the U. S. Navy, U. S. Coast Guard, and U. S. Lighthouse Service.

As to the value and need of such schools there can be no question. The schools furnished officers for many years when our merchant marine was small; and it is due in [illegible] these schools that the [illegible] enabled to expand the service as [illegible]

Not only have these schools supplied the officers necessary to man our merchant marine in the past but they will be able to furnish officers for the great merchant marine fleet we hope to maintain. It is true that the schools now in operation in Boston, Philadelphia, Seattle, and New York probably do not graduate enough to supply the demand but if advantage is taken of the law as it now stands we could have eleven nautical schools and schoolships turning out about 400 well trained officers a year at very little additional expense to the country.

It is not necessary for the government to erect an Annapolis for the merchant marine, costing millions of dollars. The people of the country are through with costly experiments. Let us get down to a real practical business basis and encourage and help our nautical schools of the country as they now stand. If we are fortunate enough to maintain our enlarged merchant marine, let us help the other states authorized by law to have schoolships—organized in that way, the demands of the service will be met. On the other hand, if we do not keep a large merchant marine, there will not be a large demand for young officers and the number of these schools can be reduced to that required to supply the demand. Not only will this system of training save thousands of dollars but, by having small units, the young men will be given almost individual instruction and in that way be much better prepared to perform the duties required of them than men who have been trained in large numbers and do not have a chance to become confident. By small units is meant a ship that accommodates from 100 to 125 cadets.

To give an idea of the work performed by these nautical schools and the calibre of young men graduated, a brief outline will be given of the course of instruction at the oldest school, the New York Nautical School, conducted on the Schoolship *Newport*.

Boys of good character between the ages of 17 and 20, whose parents or guardians are citizens of the State of New York, and who can pass the mental and physical entrance examination are admitted as cadets.

There are four classes and the course is for two years. Either deck or an engineering course may be taken. During the first six months the cadet is required to perform duty in both the engineer department and on deck; in that way a deck officer acquires some knowledge of engineering and the engineer officer becomes acquainted with the duties of the deck. The benefits derived from a course of this sort may be readily understood. The remainder of the course is taken up by specializing in the particular branch chosen.

During the academic term of six months each year, the cadets are taught seamanship, theoretical and practical navigation, such parts of algebra, geometry, and trigonometry as pertain to navigation, and nautical astronomy, ship's business, navigation laws, naval construction, hygiene, signals, and Spanish. The Spanish course was a new feature of the school started on our last practice cruise as an experiment, but as we had very good success we intend to make it a permanent subject. It should prove to be very beneficial to our officers as they will undoubtedly be in ships going to South America, Mexico, and Mediterranean Ports.

The engineer cadets are taught steam engineering, electricity, physics, mathematics, and hygiene. To keep in touch with the latest developments in machinery, boilers, and electricity, the cadets are given short courses of instruction and lectures by officials of the following companies: General Electric,

Fig. 1. New York State Nautical Schoolship *Newport* Under Sail in Light Trade Winds

Worthington Pump, Babcock and Wilcox, and Machinery Division, Navy Yard.

During the summer the cadets are usually taken on a foreign cruise lasting about four months during which time they stand watches, work the ship and are given practical instruction in seamanship, navigation, and engineering.

As we sail from port to port whenever time permits and steam only when making and leaving port, quite a number of seafaring men and others think that too much time is taken

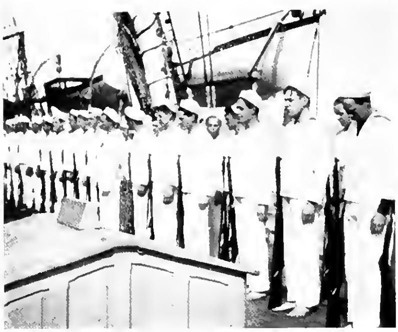


Fig. 2. Schoolship Cadets at Infantry Drill While at Sea

up in handling sails. True, there is a great deal of the spare time taken up in this instruction on a practice cruise but it is most essential in the proper training of an officer; it teaches an officer to be more observing, he has one hundred and one things to watch especially during a strong breeze; it teaches him to act quickly in emergencies because there is always something carrying away in a good blow; it teaches him to handle his vessel properly in heavy weather because sailing shipmen are always watching the seas, always looking out for shifts of wind, etc. Not only is it most beneficial in developing an all around good officer but it inspires him to live up to the highest traditions of the sea. How well satisfied we feel after close reefing the topsail during a gale! We feel that the elements have been conquered! How many of our "War Baby" officers have ever had the thrill connected with hauling out the weather topsail reef earing with the ship pitching and rolling during a gale. These are some of the experiences that have inspired our young Americans to follow the sea.

Sail has not only been most beneficial in the purpose of training our graduates but proves to be very economical in the operation of these schools. Had it not been for sail, the *Newport* would not have been able to make a foreign cruise this year on account of the cost of coal. Fortunately, though, we were able to visit the following ports:

> We sailed from the Brooklyn Navy Yard, July 5th, arriving at Portsmouth, Eng., July 31st. We left Portsmouth August 7th, arriving at Antwerp on August 9th. After giving the cadets an opportunity to witness the Olympic Games and visit the battlefields of Belgium and France, we left for Lisbon on August 28th, arriving after ten days at sea. From Lisbon we proceeded to Cascaes, Portugal, and Funchal, Madeira. Leaving Madeira Sept. 20th, arriving St. Georges, Bermuda, Oct. 19th after a month at sea. Arrived in New York on October 24th.

Aside from a professional education what can give a man a better general education than travel of this sort? There is a great deal more required than just teaching seamanship, navigation, and engineering.

Our merchant officers should have a high sense of honor, be diplomatic and courteous to foreigners, and never forget that they are representative Americans. To show that we are obtaining results in this line it might be well to quote from a letter we have received from the State Department.

AMERICAN CONSULATE
Antwerp, Belgium, August 27, 1920

The Honorable
The Secretary of State
Washington

Visit of the schoolship *Newport* of the New York State Nautical School.

Sir:

I have the honor to inform the Department that the schoolship *Newport* of the New York State Nautical School arrived at Antwerp on August 9th, 1920, with about 95 cadets. The Schoolship is commanded by Captain John S. Baylis of the United States Coast Guard. Captain Baylis called on the local officials accompanied by the Consul, and the officials returned the calls later on board the ship. Through the courtesy of the city officials the cadets were shown all over the harbor and port works of the city, and were given every opportunity to see everything in the city which could be of interest or value to them. The ship left for Lisbon on August 27th.

I was on board the *Newport* four or five times during her stay in port and was greatly impressed by the character of the work which the officers are doing in training these young men for service in the American Merchant Marine. They not only have excellent discipline on board the ship but seem to enjoy the confidence and respect of all the cadets. The course which is being followed seems like a very thorough one. Everyone who came in contact with the cadets was impressed by their appearance and my own opinion is that I have never seen a finer lot of young men on board of any schoolship training officers for the merchant marine.

I have the honor to be, Sir
Your obedient servant,
(Signed) GEORGE S. MESSERSNITH
American Consul

Fig. 3. Cadets on Shore Leave at the Moorish Castle at Cintra, the Former Home of ex-King of Portugal

General Electric Company's School of Marine Engineering

By J. Livingston Booth

Marine Engineering Department, General Electric Company

The rapid rate at which cargo vessels for the Merchant Marine were placed in service during the last three years very soon caused a shortage of sea-going engineers. Furthermore, the fact that modern high-speed turbine machinery had been adopted for driving a very large percentage of the new ships resulted in the supply of engineers who were experienced in this type of machinery being very soon exhausted, and necessitated the ships being taken to sea by men who had no previous experience with turbine machinery. In order to improve the operation of the ships, and to prevent, as far as possible, interruptions in service occurring from defects arising from faulty operation, various Marine Schools were established at the request of the United States Shipping Board in the works of some of the manufacturers of marine equipments, to train engineers in their operation and maintenance.

The General Electric Company's school of Marine Engineering was established in the fall of 1918 to meet this situation; and, although commenced as a war measure, the results obtained have been so satisfactory that the school has been maintained by the Company up to the present time, and will probably be continued until the necessity of training men has ceased to exist.

In arranging the instruction given, it was recognized that most of the training should be based on the standpoint of the operator, rather than the designer, and that the instruction should be as practical as possible. At the same time, it was considered to be absolutely essential that a sufficient insight into the theory and reasons underlying the design of the machinery should be included, to give an intelligent understanding of the apparatus, and to interest the engineers in obtaining the best and most economical results from the equipments.

The lack of understanding of marine geared turbines which existed at their first introduction, and the desirability of obtaining reliable data on the performance of new types and devices, had necessitated the establishment by the Company of a system of inspection of all vessels in service equipped with machinery of General Electric manufacture.

The work in connection with the school has been handled by that section of the Marine Engineering Department which is connected with the operation and inspection of vessels in service. As upwards of three hundred cargo vessels have been placed in service equipped with General Electric marine geared turbines, exclusive of about fifty naval vessels, a great deal of practical information on the operation of the various types in service has been accumulated. This proved to be of the greatest value in the school, for it is possible to give accurate data to engineers on the performance of each type of equipment, details of any breakdowns which have occurred, their causes and remedies.

It has also enabled a study to be made of the results obtained with the different systems of lubrication and arrangements of engine room machinery and types of turbine and gear foundations as installed by the various shipbuilders in many types of vessels.

It was found very soon after marine geared turbines were placed in service that several factors, such as the design of foundations and lubricating systems, also the method of installation and alignment, had a very important effect on the operation of the gears. For that reason the instruction given has not been confined to the operation of the machinery, but a comprehensive view has been given of the whole problem of the application and operation of ship propulsion machinery and auxiliaries, in order that an engineer may be able to recognize defects which have been found to be detrimental, and to eliminate them before they cause trouble.

COURSES

Marine Geared Turbines

A course of three weeks' instruction is given in the operation and maintenance of the marine geared turbine. Of this time, the first week is given to the turbine, the second to the gears, and the third to a study of elementary electricity and details of steam engine and turbine-driven generating sets, motors, etc., to enable engineers to handle the electrical machinery, now being used on board ship to a rapidly increasing extent. Attention is also given during the third week to the economies to be obtained by the use of electric-driven engine room and deck auxiliaries, and to the special types of motors and control apparatus which have been developed to meet the requirements of shipowners with respect to the special conditions which exist at sea.

A three-weeks course has been given on the 6000-h.p. compound geared turbine equipments for the U. S. Army Transports built at Hog Island.

A special Geared Turbine and Electric Machinery course was also given in 1918 to officers of the Naval Reserve.

The second room is equipped with extra parts of marine geared turbines, such as a wheel and buckets, thrust bearing, emergency governor, jaw and pin type of coupling, where the men assemble and disassemble these parts and become thoroughly familiar with them.

The third room is fitted up with the principal parts of the control apparatus for electric drive equipments for cargo vessels, steam-driven generating sets, motors, etc., such as would be found on board ship.

There is also kept in the school a file of detail and assembly drawings of the various

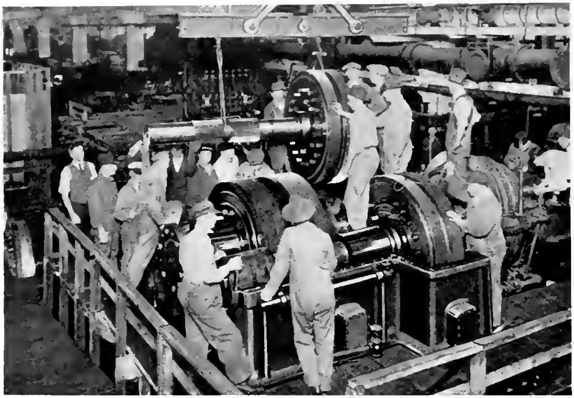


Fig 1. Class of Chief and First Assistant Marine Engineers at the General Electric Company's School Engaged in Assembling and Adjusting a 2500-h.p. Marine-geared Turbine

Electric Drive Course

A five-weeks course is given in the operation and maintenance of the main propelling electric equipments now being installed on cargo vessels.

Special courses have also been given on the electric machinery for the battleships *California*, *Maryland*, and *West Virginia*.

SCHOOL EQUIPMENT

Three rooms have been provided for the use of the school, one of which is used as a general assembly room and is furnished with tables, chairs, blackboards, etc. Lockers are also provided for the convenience of the engineers. Lectures are generally given in a separate lecture room specially fitted for [illegible] lantern slides and motion pictures.

types of marine equipment A complete marine turbine and reduction gears which can be run under steam are also reserved on the testing stand especially for the use of the school.

METHOD OF INSTRUCTION

The engineers attending the school through the Shipping Board Recruiting Service are all either Chief Engineers or First Assistants. A class therefore quite frequently includes college graduates who have just obtained their first assistant's license, and engineers who have held a chief's ticket for twenty years or more, and who have never seriously had to study a new subject during that time.

The problem of presenting the information in such a way that it will hold the attention of the class throughout the course and be retained is not any easy one. Every effort is made to assist the men in absorbing the information, and to guard against merely the accumulation of written data, which may or may not be available when required. Lectures are kept as free from technicalities as possible. All are required to take notes on the lectures, which are corrected and returned. Questions are also given on some of the lectures, the answers to which are written out at home and turned in the next morning. These are then corrected and discussed in class to clear up any errors which may have been made. Abstracts of the lectures are also given to the engineers to which they can refer should this be necessary after leaving the school.

Some of the lectures are given by the Company's engineers in charge of the school work, but most of them are by engineers who are from the various departments engaged in marine work and who are responsible for the design, assembly, or testing of the apparatus. It is considered that in this way the best instruction available is given; and that the school work could be kept abreast of the rapid development which has taken place in marine work only by the lectures being given by those actually responsible for the work. In the course on electric drive, as many as twelve of the Company's engineers are called in for some portion of the instruction. Special attention is given to a study of the importance of economy, to steam conditions, and to the theory of condensers, to enable an engineer to check the performance of his equipment and to assist him in its economical operation.

In the practical work in the shops, the engineers are required to handle the marine geared turbine under steam, and to disassemble the turbine and gears, all work in connection with this being done by the engineers. When assembling the turbine, the clearances are carefully adjusted and checked, and the instructor will frequently remove some of the shims used for aligning in order to throw the machine purposely out of adjustment and the men are required to find and correct the fault.

A written examination, and in the electric drive course both a written and oral examination, are given at the conclusion of the class, and each engineer marked on his work in the examination and also during the course.

RESULTS OBTAINED BY THE SCHOOL

Up to the present time about 520 chief engineers and first assistants have been trained through the recruiting service of the U. S. Shipping Board. About the same number of officers of the Naval Reserve were passed through the special course in marine geared turbines and electric machinery.

The Company has also given this training to a number of construction foremen from shipyards and repair yards, and others who, for various reasons, do not come within the regulations of the Shipping Board.

The special course on the army transport equipments has been given to men from the transport service, and the course on the electric machinery for battleships to men from the navy and the shipbuilders' yards.

A great deal of enthusiasm is being shown by engineers for the training received, it being realized that an opportunity is presented to obtain a more practical knowledge of the most modern marine machinery than can be obtained in any institute or college. One man paid his own expenses from Honolulu in order to attend the school; and applications have been received from ships in many parts of the world, so that there are generally as many as 500 engineers on the waiting list for the school.

The effect of the training is also evident in fewer cases being reported of defects developing as a result of faulty operation. It also usually results in close co-operation between the ship's engineers and the Company's surveyors and construction foremen; and experiences and information are passed on from ship to ship which are invaluable in assisting the operating engineer in maintaining his equipment in good condition and in obtaining the best results in operation.

Electricity on Merchant Ships

By E. D. Dickinson

Merchant Marine Section, Marine Engineering Department, General Electric Company

With the ever increasing interest that is being shown in our merchant marine, it is very gratifying to see how much serious consideration is being given to improved economy.

It is recognized that, no matter what laws any state may pass or how any particular country may endeavor to assist the owners and operators of vessels flying its flag, the operation of merchant vessels is a highly competitive commercial activity subject to the fundamental laws of trade and commerce. As the success of any commercial enterprise depends upon whether it is able to compete successfully with others in the same line of business, the question of efficiency is fundamental and ultimately may be the deciding factor as to whether certain of the competitors are forced out of action. The word efficiency is used in the broadest sense, as meaning the maximum amount of service rendered for the minimum number of dollars expended over a period of action.

In considering merchant vessels, continuity of service or reliability is probably the predominating factor, for interruption of service can be directly translated into dollars lost. The second factor in efficiency, that is, the actual cost of operating can be readily estimated in dollars per ton-mile of cargo transported. This cost has increased very markedly in the past few years and because of this and also because it may be expected to become even greater, it is apparent that we should give more attention to economy or efficiency of operation than has been necessary in the past.

The general use of electricity as a means for transmitting power has increased and will continue to do so because, with apparatus in every way suitable for the service and properly installed, it is an essential means of increasing the efficiency of a ship. Interruption of service and subsequent delays, barring accident, can be eliminated, thus assuring that the vessel can be kept in service approximately 100 per cent of the time.

In studying costs of operation many details must be given due consideration. These may be roughly divided into fuel consumption, maintenance or upkeep, and time saved in handling [illegible]. A higher efficiency will be realized by [illegible] the services of the more competent [illegible] engineers who are attracted to [illegible] electrical machinery.

The advent of the motorship has done much to demonstrate the great saving in fuel that can be realized by the use of electrical auxiliaries. The high fuel economy shown by ships of this class is due in no inconsiderable degree to the use of electrically driven auxiliary machinery, both on deck and in the engine room. A reduction in fuel consumption may be expected on any cargo boat now equipped with steam driven auxiliaries by the substitution of electrically driven auxiliaries for deck and engine room. The gain that may be realized will vary with different ships, depending upon the existing steam driven equipment.

It is pertinent to the discussion on maintenance or upkeep to point out that the application of electricity has suffered not by its use, but by its abuse, in other words, electricity, which serves us so faithfully in its many applications, often where the lives of men would be jeopardized by its failure or interruption, has been discredited in some instances by improper design or application.

The various factors entering into the design and manufacture of electrical apparatus are well understood and the necessary precautions which must be taken in order to adapt any piece of machinery to the service for which it is intended are known to the engineers who have made a special study of the subject.

Properly designed motors are operating in mines where the surrounding atmosphere is damp and in some cases where the water contains a considerable quantity of sulphuric acid. For shipboard application, where so much depends upon continuity of service, it is difficult to imagine a single condition that would warrant the use of electrical apparatus which is not designed to meet the conditions that may be expected at sea. Neglect of fundamental details may result in the failure of electrical equipment at a critical moment and mean considerable immediate loss to the owner or operator of the vessel and the general and absolutely unwarranted discrediting of the use of electricity.

It is unfortunate that many people believe a certain amount of repairs to their machinery to be inevitable. This is fundamentally wrong, as all repairs are traceable to some specific cause and a general study shows that the necessity for making repairs may result from one or more of the following:

(1) Improper design
(2) Imperfect installation
(3) Carelessness in operation

If the design is considered in all its details, the equipment will be properly proportioned for the service and in every way suitable for the work. Electrically operated auxiliaries, because of their few moving parts, can be made so rugged, simple, and "fool-proof" that trouble incident to careless operation may be reduced to a minimum. Shipbuilders, owners, and operators should co-operate with the manufacturers to assure proper installation of apparatus. If this is done the electrical apparatus will have indefinite life.

Electrical apparatus is either right or wrong for the service. If it is wrong, it will be a continual source of expense. If it is right, it will operate indefinitely without interruption and will require only periodic cleaning and the necessary lubrication for the bearings. With correctly designed and properly insulated generators or motors, the temperature will be maintained below that which would be destructive to the insulation; therefore, if the machines are kept clean, the ventilation unimpaired, and the parts subjected to no external mechanical injury, they should have indefinite life.

In making comparisons, the first cost of electrical equipment for ships must not be the deciding factor. It is a recognized fact that equipments which are the cheapest in first cost often prove by far the most expensive after a very short period of service. But little difference will be found between the first cost of complete electrical and steam equipments, and in making comparisons it must be borne in mind that the cost of steam piping with the attendant fittings, special bends, and necessary supporting brackets far exceeds the cost of cables.

Improvements in the efficiency of operation that can be secured by the use of electricity apply to every vessel. The gains that can be realized in passenger vessels are of considerable magnitude. Each particular ship should be the subject of special study. In many cases gain can be shown by driving propellers electrically. This becomes more evident with the increased size of the vessel and is especially the case where it may be intended to operate for certain months on one schedule and for another period of the year on a different schedule.

The use of electric motors makes it feasible to operate propellers at the most efficient speed with a resultant great saving in fuel consumption. In passenger vessels very serious consideration should be given to the added reliability that is secured by having two or more main turbines, any one of which can drive the propeller motors.

In considering the use of electric propulsion for merchant vessels, the perfect showing of the collier *Jupiter* over a period of seven years must be recognized. While it is true that this is a naval vessel and for that reason the machinery might be expected to receive better care than would be the case in the average cargo boat, nevertheless it is a fact that she has performed her arduous duties without interruption and no precautions have been taken other than would be the case in the introduction of any new form of machinery. The machinery on this boat has demonstrated the reliability of properly designed electrical apparatus.

Instances where electrical apparatus has failed due to imperfect design and installation should be considered only as demonstrating "how not to do it electrically," for the reason that when the facts are known these cases will constitute no argument against the use of electricity if properly applied.

In studying the practicability of using the oil engine for any given ship earnest consideration should be given to electric propulsion. Study of specific cases has shown that the employment of two or more oil engine driven generators running at considerably higher speed than the propeller and driving it by an electric motor works out to have as low first cost as the direct connected oil engine even in comparatively small sizes. In larger vessels it makes the use of the oil engine practicable where the power required is considerably greater than that developed by any engine so far contemplated. There is always the very great factor of added reliability, for should any one of the engines require adjustment or inspection while at sea it could be taken out of service for the necessary time and the speed of the ship would be only slightly affected. This would allow the use of very low grade oils, as the routine could be so established as to permit the shutting down periodically of each engine to clean valves, etc. The engines would not require complicated reversing mechanism, large air storage bottles, nor additional compressors.

The purpose of this article is to show that shipowners in this country have a means available for improving the economy of their vessels so as to better fit them to meet foreign shipping competition.

Cylindrical Return-tube Boilers

By W. F. Carnes

Bethlehem Shipbuilding Corporation, Ltd.

General Construction

The cylindrical marine boiler, sometimes called the Scotch boiler, has been in general use for some fifty years and still finds general favor for use in ships, although its weight, size and amount of water carried are much greater than in other types of boilers. It is made up of several parts of different materials; the shells, combustion chambers, and furnaces are of steel plates, the stays of high-grade steel bars, the rivets of mild steel, and the tubes of lapwelded charcoal iron. The shells of boilers less than 11 ft. in diameter can be made in one plate; those of boilers between 11 and 15 ft. in diameter can be made in two plates. When the boiler exceeds 15 ft. in diameter and is of high pressure, say 220 lb., it is advisable to make the shell in three plates, owing to the thickness and weight. In all cases it is necessary that the boiler be made not longer than 12 ft. to meet the width of existing mill rolls. In all first-class boiler work, where the steam pressure is above 100 lb. per square inch, the seams of the shell plates are made by butt straps fitted one inside and one outside, the three plates being riveted together by two or three rows of rivets as shown in Fig. 1. These rivets are usually driven by hydraulic power. The thickness of the shell plates is governed by the percentage of strength which can be obtained at the joints. This may be as high as 84 per cent of the full section of the plate by using three rows of rivets.

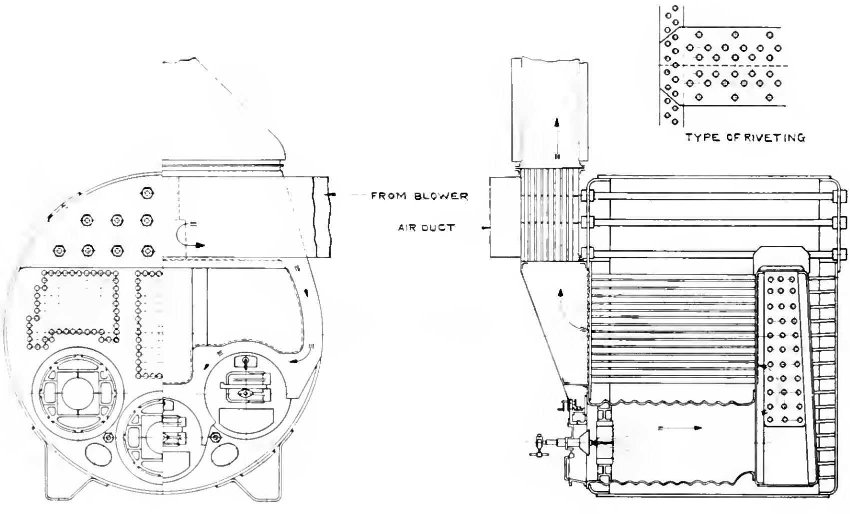


Fig. 1. Return-tube Marine Boiler, Showing Details of Construction Together with Oil Burners and Arrangement for Forced Draft with Pre-heated Air

The heads or end plates of the boilers, which are flanged to meet the shell, are attached by a double row of rivets. The furnaces are cylindrical, made out of one plate welded and corrugated by means of rolling in special machinery. Due to these corrugations, comparatively thin plates can be used, the thickness varying from $\frac{7}{16}$ to $\frac{11}{16}$ of an inch according to the size and working pressure. The inner ends of the furnaces are flanged outward, having a special shape at the bottom which enables them to be withdrawn without disturbing the front plating of the boilers. In some cases the outer ends of the furnaces are made straight and the heads flanged outward for attachment. The method generally used by the Bethlehem Shipbuilding Corporation is to flange the outer ends of the furnaces as well as the inner ends and thus avoid flanging the openings in the front heads.

The combustion chambers to which the inner ends of the furnaces are attached are made to a shape to suit the radius of the boiler shell and inner ends of the furnaces. The sides and backs are supported by means of stays screwed into the plates with the ends riveted over or fitted with nuts; the tops are supported by plate girders. Where forced draft is used, an independent combustion chamber is provided for each furnace. In boilers where lighter weight and cheaper construction is required and the combustion is by natural draft, it is a common practice to connect all the furnaces to one chamber.

It is very important when designing the boiler that ample spaces be provided between the combustion chambers, the shell, and the back head of the boilers; also over the tops of the furnaces and between the tubes, both to facilitate the circulation and free evaporation of the water and to provide necessary access to the inside of the boiler for examination and cleaning. Manholes are usually provided for this purpose in the shell and in the heads between the furnaces.

The fire tubes are fitted between the combustion chambers and the front heads. The gases, on the way to the uptakes, pass through these tubes which vary in diameter from $2\frac{1}{2}$ to 3 in. A certain number of these tubes are screwed into the plates to form stays for the plates.

Smokeboxes constructed of steel plates are attached to the front heads of the boilers. These are fitted with hinged doors having openings the full width of the nests of tubes. These doors are used to give access to the tubes for sweeping out soot or making repairs.

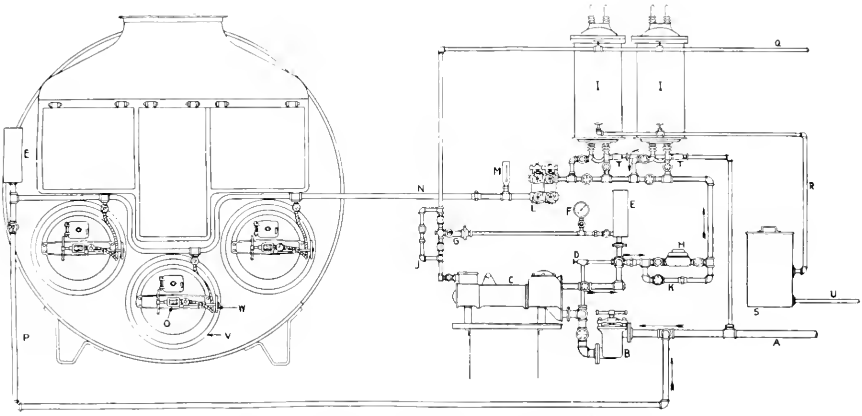


Fig. 2. Arrangement of Dahl Mechanical Fuel Oil Burning System

Furnace Fittings

The fronts for natural draft are usually made of steel plate; where forced draft is used they are made of cast iron with passages for regulating the air supply, and are fitted with hinged doors for fire and ash pits. The insides of the fronts are fitted with air-cooled baffle plates, which protect them and prevent radiation. The grate bars are usually made of cast iron, supported at each end by cast-iron plates fitted to the insides of the furnaces. The bars are usually made from $\frac{1}{2}$ to $\frac{3}{4}$ of an inch wide with air spaces between, varying from $\frac{3}{8}$ of an inch for pea coal to $\frac{5}{8}$ of an inch for soft coal. The length of the grate bars varies from 5 ft. for forced draft to 6 ft. for natural draft, although this length may be increased if the furnaces are of extra large size and the grate not too high from the fire-room floor. Bridge walls are provided at the inner ends of the grate bars. These are usually made up of fire brick on cast-iron supports.

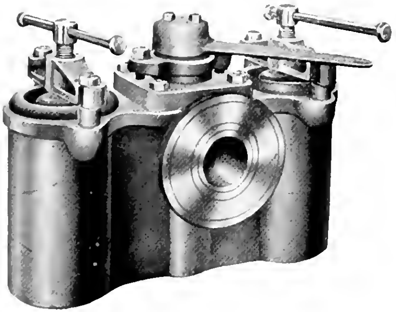


Fig. 3. Dahl Fuel Oil Suction Strainer

Mountings

The following mountings are usually fitted to the inside of the boiler: A dry pipe under the main steam outlet to prevent a rush of water from being carried over to the engine or turbine; pipe for conveying the feed water from the check valve and distributing it over a large area of water surface, small holes being drilled throughout the length of the pipe for this purpose; surface blow-off pipe and scum pan, which is placed below the working water level and is used for blowing off the scum which collects on the surface of the water; a bottom blow-off pipe which runs from the valve on the shell to the bottom of the boiler for the purpose of blowing out all water when necessary for emptying, or part of the water when necessary to reduce the salinity or impurity of the boiler contents.

To prevent corrosion, zinc plates are usually fitted to the inside of the boilers; these are placed in baskets attached to the stay bars and should be distributed over the whole interior of the boiler below the water line. The usual amount of zinc plates fitted is one square foot per hundred square feet of heating surface. Means should be provided for assisting the circulation of the water when raising steam. With coal fuel this is done by means of a pump drawing the water through the blow-off pipe at the bottom of the boiler and discharging it back through the feed pipes; another method is to fit a hydrokineter, which is a modified type of injector, inside the boiler and to furnish steam either from the shore or an auxiliary boiler on board ship. When oil fuel is used the water usually heats up uniformly and does not require this assistance.

External Fittings

The external fittings consist of the following: Main steam stop valve, independent auxiliary steam stop valve, duplex spring-loaded safety valves, a main and an auxiliary feed-water check valve having a stop valve between the check and the boiler for closing in case of repairs, a surface blow-off valve and bottom blow-off valve, a column fitted with glass water gauge and connected by means of copper pipes with the steam and water spaces, three gauge or try cocks fitted directly to the boiler shell, steam pressure gauge and valve, salinometer cock for testing the density of the water.

Boiler Supports and Attachments

The boilers are supported upon steel plate foundations riveted to the ship's structure. These are either saddles made to conform to the shape of the boilers, upon which they rest and are held down by forged rods, or fore and aft girders upon which the boilers are supported by plate brackets riveted to the shells. These brackets are used also for holding the boilers in place.

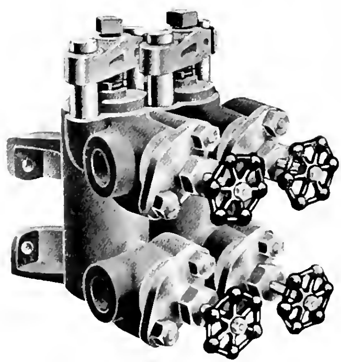


Fig. 4. Dahl Fuel Oil Discharge Strainer

Boiler Covering

When boilers and connections have been tested by hydrostatic pressure, and found to be perfectly tight, they are covered with magnesia or other insulating material not less than 2 in. thick This is usually held in place by galvanized steel sheets.

Draft

Where the boilers are of ample capacity and simplicity in working is desired, natural draft is used for the combustion of the fuel. The intensity of this draft can be varied considerably by adding to the length of the smoke stack. The amount of coal burned with natural draft is about 14 to 15 lb. per square foot of grate area. Where high powers are required from the boilers, it is customary to increase the fuel combustion by fitting forced draft, when the amount of coal burned is increased to 28 or 30 lb. per square foot of grate.

There are several systems of forced draft. The one most generally used in merchant vessels is the hot-air system, commonly known

Fig. 5. Dahl Fuel Oil Heater

as the "Howden." This is shown in Fig. 1 and consists of vertical tubes fitted in the uptakes of the boilers through which the hot gases pass after leaving the fire tubes. The air is supplied by a blower discharging on the outside of the heating tubes and passes through passages in the smokeboxes to the furnace fronts, where the supply to the furnaces is regulated by means of the dampers in the fronts. This hot-air draft is applicable to both coal and oil fuel. There are other systems, such as the Ellis-Eaves induced

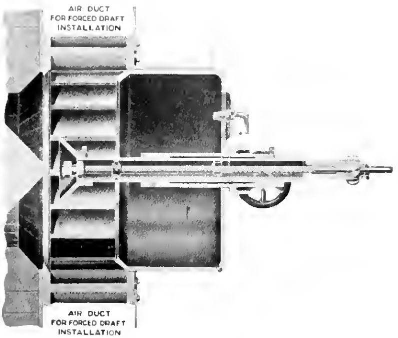


Fig. 6. Bethlehem Furnace Front for Either Forced or Natural Draft Fitted with Dahl Burner

draft, which latter consists of a suction blower so placed as to draw the hot gases from the fire room through furnaces and fire tubes up through the air heating tubes and discharging the gases up the smokestack. This, at one time, was quite popular in steam vessels but is not often used now. Another method is to fit steam jets at the base of the smokestack; this method is used only occasionally on yachts or tugboats plying in fresh water or where fresh water is readily obtainable to make up the loss.

Fuel

Up to within the last few years coal was almost invariably used for fuel, but it has been found that oil is much more economical, as the number of attendants is considerably reduced and less bunker space is required in the ship for stowage of oil, the space saved being used to increase the cargo capacity. The efficiency of the boiler is also considerably increased as the steam pressure does not fluctuate as is the case where coal is used and the fires have to be frequently cleaned, the steam pressure being constant over an indefinite period.

There are various systems in use for burning oil, the principal one used a few years ago for atomizing the oil being by means of steam or compressed air. This method has been almost universally abandoned and the atomization is now accomplished by pressure only, pumps being fitted which force the oil into the burners at a pressure suitable for the grade of oil to be burned. This pressure may vary from 30 to 180 lb. or more per square inch. The amount of oil consumed per horse-power hour varies from 1.1 lb. in multiple expansion engines to 0.9 in reduction geared turbines.

One of the best arrangements of mechanical atomizing is the Dahl system, which is manufactured by the Bethlehem Shipbuilding Corporation. The outline of the front and burner are shown in Fig. 1. Fig. 2 shows an arrangement of the Dahl system, of the piping heaters, etc., usually furnished for a marine boiler; Fig. 3 shows a suction strainer; Fig. 4 shows a discharge strainer; and Fig. 5 shows a heater. Fig. 6 shows a Bethlehem combination furnace front suitable for natural or forced draft. The type of pump used for feeding boilers, and for fuel pressure, as manufactured by the Bethlehem Shipbuilding Corporation, is shown in Fig. 7.

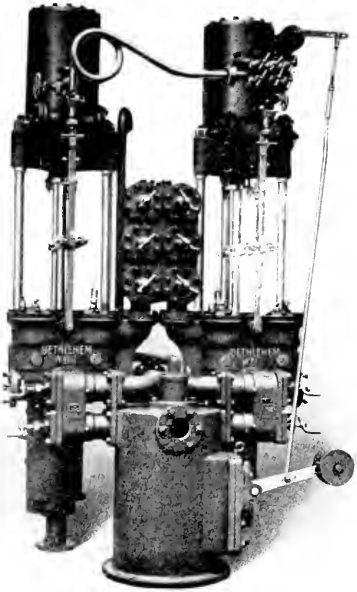


Fig. 7. Pair of Bethlehem-weir Direct-acting Feed Pumps with Float Tank and Automatic Control Gear

Fig. 1 shows a return-tube boiler 15 ft. diameter by 11 ft. 9 in. long, suitable for 220-lb steam pressure. This is a very common size of boiler used at the present time, the weight of one being about 62 tons, and three units of this size are usually fitted in ships of 2800 horse power.

Where the amount of power required is large and space is limited, as in the case of large passenger ships, boilers are often made double ended, that is, they can be fired from each end; these are usually made from 17 ft. to 22 ft. long. A considerable saving in space and weight is obtained with the same amount of heating surface with this type of boiler.

Water Tube Marine Boilers

By W. M. McFarland
Manager, Marine Department, Babcock and Wilcox Company

The boiler described in this article is an evolution and adaptation from the Babcock & Wilcox stationary boiler for land purposes to render it suitable for use on board ship. After a period of development, the manufacture of this type of boiler was begun in 1895, and it is interesting to note that some of the boilers built in that year are still in service. A set installed in 1896 was replaced by a new set in the fall of 1920, having given twenty-four years service

As shown by Fig. 1, this boiler consists of a bank of tubes inclined at an angle (usually 15 deg.) and sub-divided into a number of sections. Each section consists of two boxes, or headers, connected by tubes which are expanded into bored seats in the header. The headers are corrugated so that the tubes are "staggered," thus preventing direct lanes for the escape of furnace gases. At the top of the back header a circulating tube connects the header with a steam and water drum which is at the front and above the front headers, with which it is connected by a series of nipples. The lower ends of the front headers are connected with a cross box, or mud drum, through which the contents of the boiler can be emptied. In each header opposite a four-inch tube or a group of two-inch tubes is a hand hole closed by a plate and dog or bridge. Through these hand holes complete access is given to the inside of the header and to the tubes for internal cleaning, expanding, and, in the case of renewing a tube, for its removal and replacement.

The back headers are supported on an "I" beam which runs across the boiler, and it is to be noted that they rest upon this beam without being secured to it. The result is that each section is free to expand independently of every other one, thus giving the boiler a remarkable and unusual degree of elasticity, which is impossible where the tubes are expanded into stiff water boxes running clear across the boiler.

It will be noted that vertical baffles extending about two-thirds of the way across the bank of tubes compel the gases to cross the tubes three times in their passage from the furnace to the uptake, thereby insuring the thorough sweeping of the gases over every part of the tubes. A roof baffle of light, highly refractory tile extends about two-thirds of the length of the furnace from the front, preventing the entrance of the gases into the tube bank until after combustion is complete. Owing to the upward inclination of the tubes, the volume of the furnace increases toward the exit of the gases, thus providing for the increased volume due to the high temperature of the combustion. When the boiler is fitted for burning oil fuel, the sides, bottom, back, and front are all lined with brick so that the conditions are ideal for perfect combustion.

Fig. 1 also shows a superheater which is placed above the first and second passes of the gases in a position where the gas temperature is high enough to secure a considerable degree of superheat from a moderate amount of surface. This location is much more efficient than the uptake with low temperature and exposure to atmospheric corrosion, and also to positions further along toward the exit of the gases where the low temperature requires much greater surface.

The steam and water drum is at the front of the boiler and is supplied with the usual fittings and mountings. It is to be noted that the drum is away from the hottest part of the boiler, thereby contributing to a steady water level.

The circulation is simple and direct and all the water in the boiler partakes of the circulation, there being no "dead" spaces. In consequence of this active circulation the amount of water carried in the boiler is very small as compared with the older type of shell boilers, the amount varying from five to seven pounds per square foot of heating surface as against twenty-five to thirty pounds.

Advantages

The special advantages of the marine boiler herein described may be summarized as follows:

(1) Lightness but with scantlings sufficient to give reasonable longevity.
(2) An adequate amount of water so that inattention to or failure of the feed supply will not immediately cause trouble.
(3) Accessibility for cleaning and repairs on both water and fire sides.
(4) Straight tubes with no screw joints, all the joints being expanded.

(5) No cast metal, either iron or steel, subjected to pressure.
(6) Ability to raise steam quickly.
(7) High economy of evaporation.
(8) Economy of space.
(11) Ability to stand abuse; that is, the boiler is of rugged construction and does not require skilled mechanics to run it.
(12) Safety against disastrous explosion.

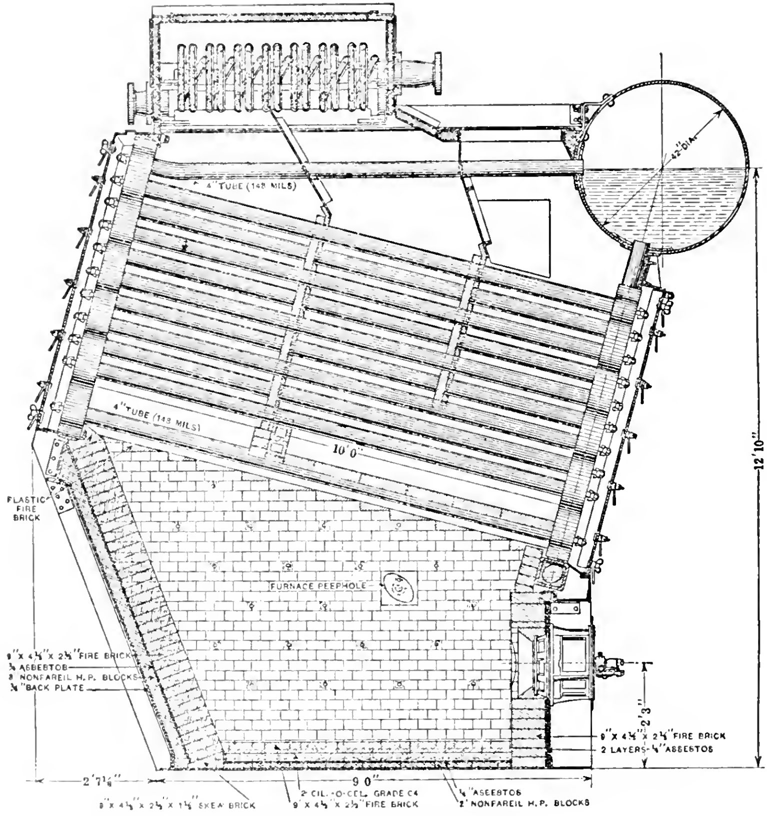


Fig. 1. Sectional Side Elevation of Water Tube Marine Boiler, Showing Tubes, Steam and Hot Water Drum, Superheater, and One Oil Burner

(9) Interchangeability of parts and the use of regular commercial sizes, so that many repair parts can be secured anywhere.
(10) Ability to stand severe forcing without injury.

Repeated tests by independent engineers have shown that steam can be raised from cold water to a pressure of 200 lb. per square inch in about fifteen minutes. While it is not necessary, as a rule, to raise steam so quickly, this quality may be of the greatest service in case of necessity, such as a sudden storm when at anchor or a fire on the dock where the vessel is lying.

Boilers for Fast Passenger Steamers

Where saving of weight and space are of the greatest importance, as is usually the case in naval vessels, the boilers are built with tubes two inches in diameter, the weight being from twenty to twenty-five pounds per square foot of heating surface, including water. Boilers of this type are used for high powered passenger steamers.

Boilers for Merchant Vessels

In freight carriers or other vessels where the saving of weight and space need not be carried to the last extreme, boilers with four-inch tubes are usually employed, as the maintenance of cleanliness, exterior and interior, is easier with the larger tubes. Boilers of this type will weigh from thirty to thirty-six pounds per square foot of heating surface, including water.

Economy and Capacity of Boilers

A great many tests of boilers built for the Navy have been made by Boards of Naval officers, thus supplying data of unquestioned accuracy and reliability. In some coal burning tests the rate of combustion for several hours was 70 pounds per square foot of grate surface per hour, which is the highest rate of driving ever attained with any water-tube boiler when using coal as fuel. The evaporation was 14.76 pounds per square foot of heating surface. The record of an oil fuel test shows that the boiler was driven at an even

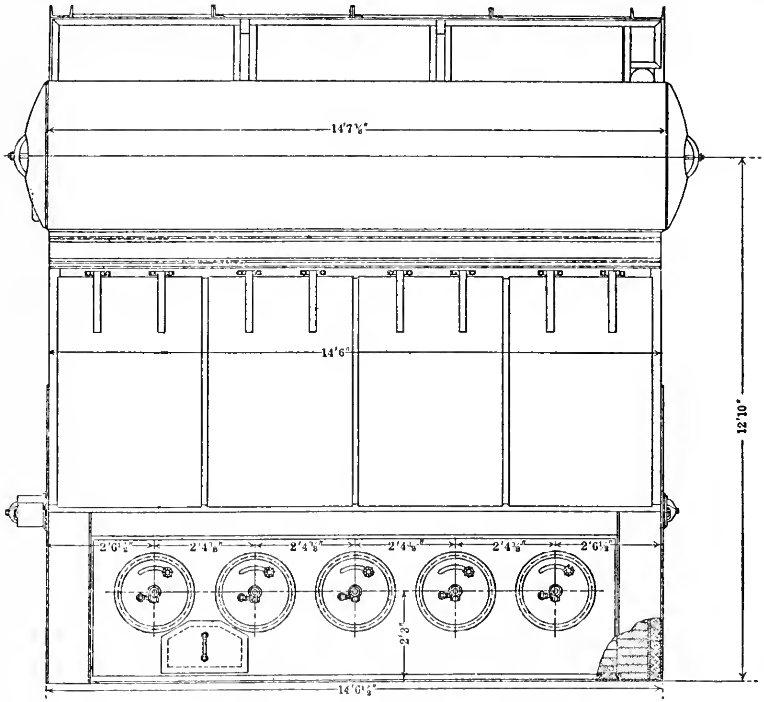


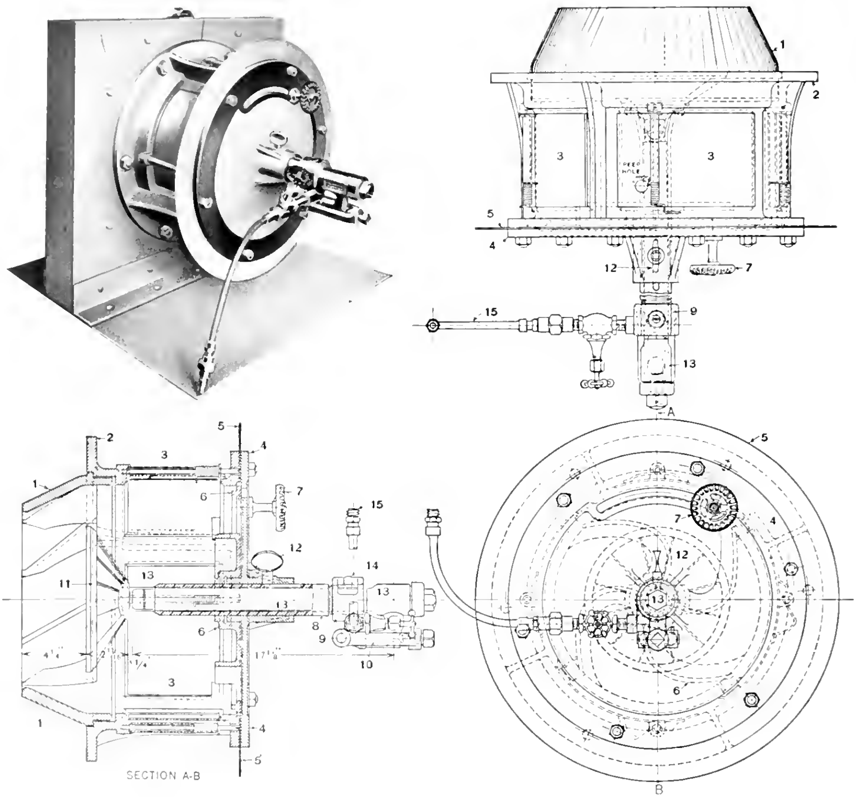
Fig. 2. Front Elevation of the Babcock & Wilcox Marine Boiler Shown in Fig. 1

higher rate, namely, 1.23 pounds of oil per square foot of heating surface per hour, which gave an evaporation of 18.7 pounds of water per square foot of heating surface per hour.

Facility for Cleaning and Repair

Every part of the boiler is readily accessible, thus making it easy to clean and repair. The

It is worth noting, as showing the small amount of repairs, that the U. S. S. *Marietta* fitted with Babcock & Wilcox boilers, which accompanied the U. S. S. *Oregon* on her famous trip "around the Horn" from San Francisco to Florida at the time of the Spanish War, a distance of about 13,000 miles, only needed a few fire bricks after this long voyage.



Figs. 3 and 4. Photograph and Drawings of the Babcock & Wilcox Oil Burner

interior of the tubes can be cleaned from outside the boiler. There is no "back connection" to be cleaned. As a rule, the only repairs are the occasional renewal of tubes, where all the work is done outside; and the renewal of furnace firebricks, where there is [illegible] work.

Oil Burner

The oil burner shown in Figs. 3 and 4 is of the type known as "mechanical atomizing." This means that the oil spray is produced by mechanical pressure on the oil and not by means of mixture with steam or air, as was the case with the first oil burners used.

There are two very essential features in the oil burner, one the device for producing the oil spray, called a "sprayer plate," and the other, the air register, for causing an intimate admixture of air with the oil spray so as to secure complete combustion.

The sprayer plate consists essentially of a central orifice, through which the oil is finally expelled, with four slots tangential to this orifice and communicating with an outer circular channel which itself is in communication with the barrel of the burner. The oil under pressure, going through tangential slots to the central orifice, receives a rapid whirling motion, which, after passing through the orifice, causes it to break into a conical spray of very fine particles.

The air register consists of a number of vanes set at an angle and so arranged as to cause a whirling motion of the air, which produces a thorough mixture with the oil and secures complete combustion.

These oil burners are arranged to be used with either natural or forced draft, and provision is made for adjustment so as to obviate smoke and pulsations. The apparatus is so designed that a burner can be very quickly removed for cleaning. A strainer is provided as part of the burner barrel to insure cleanliness of the oil.

The quantity of oil which can be burned efficiently depends upon the size of the orifice, the oil pressure, and the amount of air and air pressure. The latest development of the burner manufactured by the Babcock & Wilcox Co. has been in the direction of very large capacities per burner, and recent tests have given a record of more than one ton of oil per hour per burner.

Thus far the efficiency of oil burners has been determined only in connection with the evaporative performance of the boiler to which the burners were attached. Babcock & Wilcox burners in connection with boilers of the same make and with White-Forster boilers, have attained efficiencies exceeding 80 per cent.

Oil Fuel

Since the advent of highly efficient mechanical atomizing burners, oil has become very popular for marine purposes. The advantages of oil fuel over coal for marine boilers are as follows:

(1) Greater convenience and uniformity of operation.

(2) Greatly increased cleanliness.

(3) Increased bunker capacity due to greater thermal value.

(4) Ability to utilize double-bottom and other spaces not available for coal.

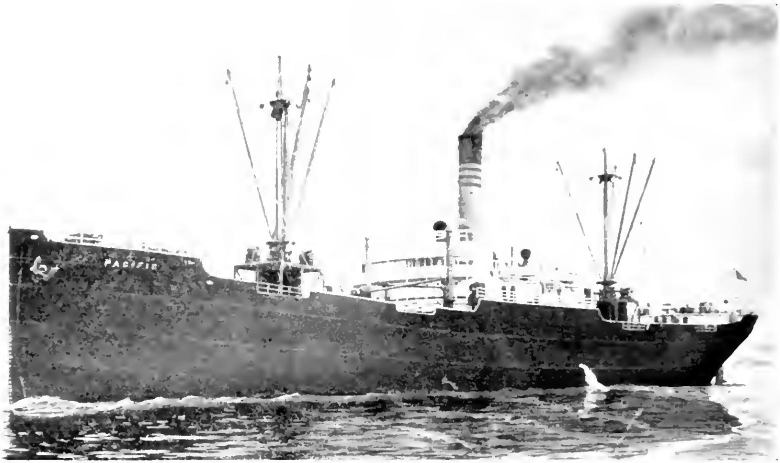
(5) Greatly reduced fireroom force.

(6) Ease and rapidity of taking fuel on board.

(7) Higher efficiency of boiler due to uniform conditions of working, absence of opening doors for firing, and no loss from ashes and unburned fuel.

(8) Absence of the nuisance of ashes and cleaning fires.

(9) Elimination of "stand-by" losses.



The *Pacific* is the first merchant ship in the world to be equipped with a high-speed turbine, double-reduction gear drive. The turbine is of the Curtis impulse type and the gears of the two-plane type. Up to October 1, 1920, this vessel has steamed over 230,000 miles

The *Robin Gray* is an Express Freighter Propelled by a 3000-h.p. Turbine Geared Unit of the Two-plane Double-reduction Type. The boat entered the service in the early part of 1920

Steam Superheaters in Merchant Ships

By H. B. Oatley
Chief Engineer, Locomotive Superheater Company

Superheaters as used in marine service at the present time may be divided into two classes:

Live-gas superheaters are those exposed to the gases of combustion which, after leaving part or all of the superheater, again are in contact with the evaporating surface.

Waste-gas superheaters are those that are exposed only to the gases which have left the boiler evaporating surfaces.

Successful superheater equipment of efficient design must be located in a zone where the gas temperatures and velocities are relatively high, thus providing better heat transfer and less possibility of soot being deposited upon the surfaces of the superheater.

For cross-drum water-tube boilers, the superheater is generally located at the top between the first and second pass, as shown in Fig. 1. This superheater is of the live-gas class, and is in a zone of gas temperatures ranging between 1000 and 700 deg. F.

For Scotch boilers, the fire-tube type of superheater is of the live-gas class, as shown in Fig. 2, and is in world-wide use. The gas temperature surrounding the units ranges between 1000 and 500 deg. F.

For both water-tube and fire-tube boilers, some installations have been made in this country of the low-degree waste-gas superheater, shown in Fig. 3, although its use abroad was discontinued a decade ago. It usually is placed in a gas temperature zone ranging from 550 to 440 deg. F.

In order to make clear the heating capacity afforded by the two classes of superheaters,

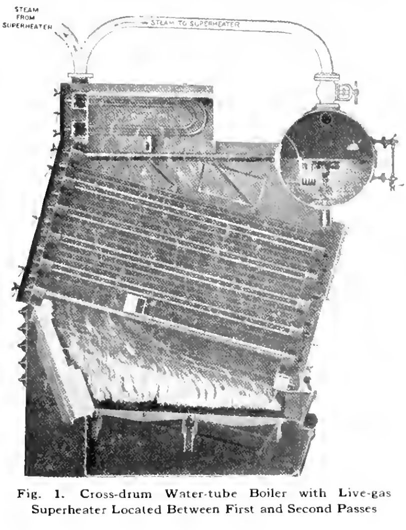


Fig. 1. Cross-drum Water-tube Boiler with Live-gas Superheater Located Between First and Second Passes

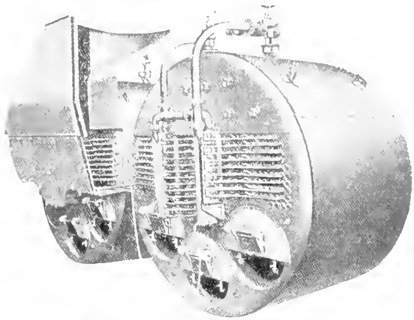


Fig. 2. Scotch Boiler with Fire-tube Type of Live-gas Superheater

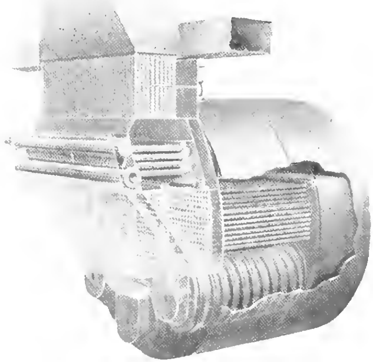


Fig. 3. Boiler Equipped with Waste-gas Superheater

Figs. 4 and 5 are shown. Fig. 4 shows the gas temperature curve, under good combustion conditions, for the usual type of vertically-baffled cross-drum water-tube boiler. The zone of superheater location is shown and the shaded area indicates the temperature difference available. Fig. 5 is a similar diagram for a Scotch boiler. The location of the units of a fire-tube superheater is shown, and the "temperature head" is indicated by the shaded area. The location and temperature head of a waste-heat superheater is indicated. In each illustration there is shown a curve of gas temperatures for poor combustion conditions. The advantages of having a liberal margin of superheating capacity, by locating the superheater in an adequately high gas temperature zone is evident.

The advantages of keeping superheater surfaces clean need not be emphasized. The effect, however, of soot and scale formation necessarily more severely affects the superheater which has the lesser capacity or smaller temperature head. The necessity of having reserve capacity for producing the specified superheat under conditions existing at sea, which may add considerably to the amount of moisture and sometimes even solid water coming to the superheater, is very well recognized by those who have had experience with this problem.

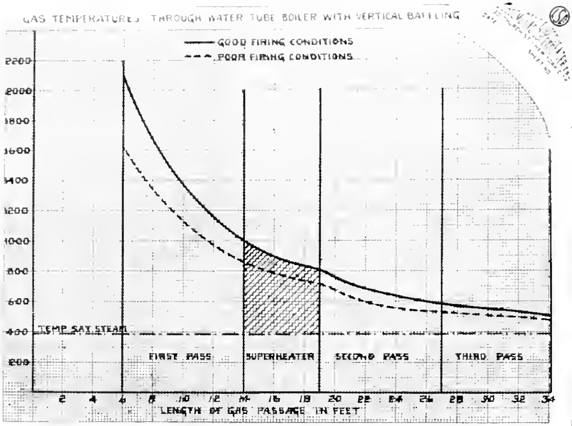


Fig. 4. Gas Temperatures Through Water-tube Boiler with Vertical Baffling

Boiler efficiency is noticeably improved by the use of superheaters. In water-tube boilers, the use of a live-gas superheater does not require any sacrifice of boiler proportions to favor the superheater, and the uptake temperature is lowered by the addition of the superheater. In Scotch boilers of the best design, the gases leave the tubes at about 500 or not more than 550 deg. F. The installation of a fire-tube superheater will reduce the gas temperature at this point 50 or even 75 deg. F. In boilers that are not so well designed, the reduction may be more by varying the superheater proportions.

A waste-gas superheater is indicated in Fig. 5. In a well-designed boiler it is subjected to limited gas temperatures and 20 to 25 deg. F. of superheat is the practical limit for even good operating conditions. The designers of this class of superheater therefore naturally

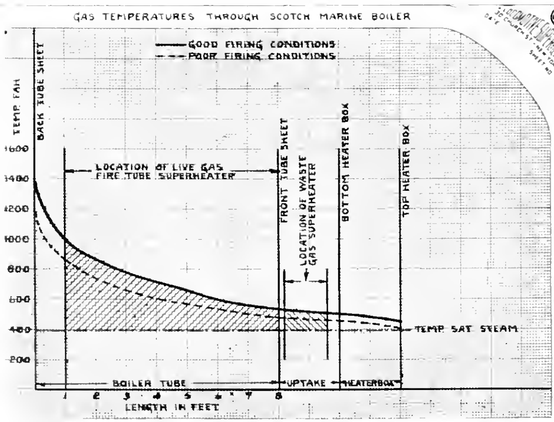


Fig. 5. Gas Temperatures Through Scotch Marine Boiler

desire that the boilers be so proportioned as to provide an undesirably high uptake temperature in order that these degrees of superheat be obtained under adverse operating conditions.

Units (or elements) of superheaters in marine practice are either of the bare-tube or covered-tube type, about 80 per cent being of the former. The covered tube has been applied only in American built vessels. The bare-tube is more easily kept free from soot and ashes than is the covered-tube because the ribs on the latter collect and retain soot and ashes. The sustained superheating capacity of any unit is largely affected by the collection of soot and dirt on the outside, as well as by the scale on the steam-touched side.

Units are connected to headers either by a permanent rolled joint, or by a detachable joint having metal-to-metal or recessed gasket construction. When unit pipes are rolled into the header there is required an opening or hand-hole opposite the tube-end which necessitates a plate or plug. With the detachable form of joint, no additional opening is required.

Unit pipes are either continuous or joined. When continuous, they are bent either to a "U" or hairpin form, or are forge-welded together. The forged type of return bend is used where pipes are required to be close together as in fire-tube superheaters. When unit pipes are joined they are rolled into a box-form of cast-steel return bend, which has the usual hand-hole and plug.

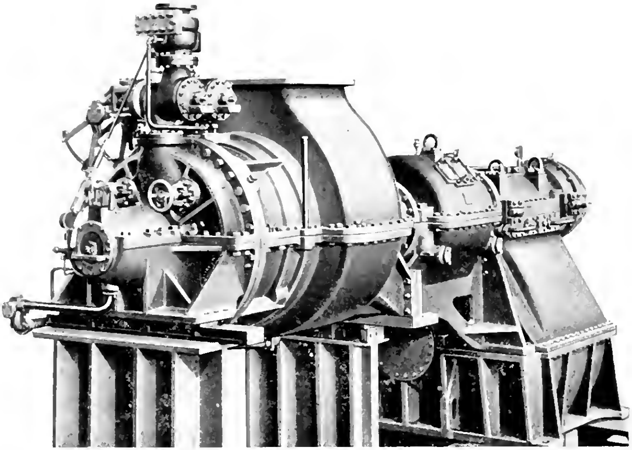
Headers are of seamless steel tubing, cast steel, or semi-steel. In section they are either rectangular or circular with flattened sides. The flattening permits of an easier rolling of tubes and fitting of hand-hole plugs and gaskets.

Table 1 will bring out the characteristics of the three classes of superheaters which have been described in some detail.

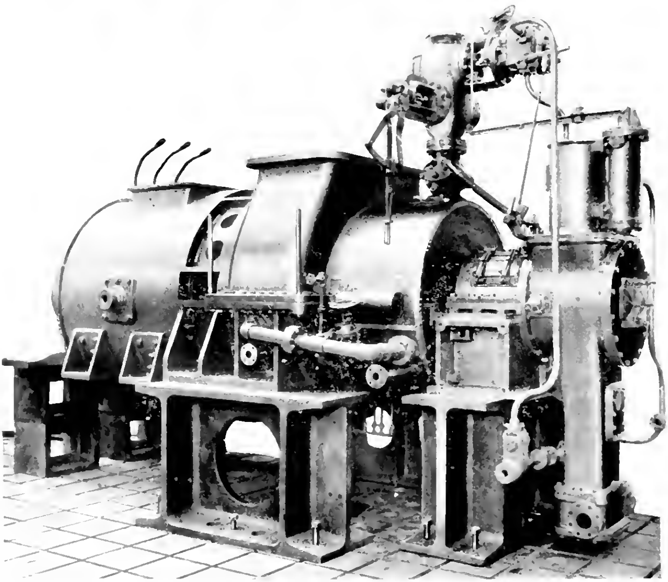
The function of the superheater in the engineering field is twofold: to produce economy and increase capacity. When used for marine purposes in connection with commercial vessels, its purpose usually is fuel economy. However, if desired, the superheated steam vessel may be operated at a higher power output than can be obtained with saturated steam. Its use on naval vessels is generally to provide increased horsepower or decreased boiler size. Superheated steam has been adopted, and is considered essential, for all kinds of steam power plants on land. The advantages of highly superheated steam are well known, and its increasing use in marine service, particularly during the past two years, indicates that the near future will see its position as firmly established on shipboard as it is in other fields.

TABLE I

	Fig. 1	Fig. 2	Fig. 3
Class of Superheater	Live-Gas	Live-Gas	Waste-Gas
Gas Temperature Range	1000° to 700°	1000° to 500°	550° to 440°
Form of Unit	Bare	Bare	Covered
Outside Surface of Unit	Smooth	Smooth	Corrugated
Connection to Header	Permanent	Detachable	Permanent
Hand Holes in Header	With	None	With
Unit Pipe Bend	Bent	Forged	Rolled in Box
Header Material	Steel	Cast Steel or Semi-steel	Steel



General Electric Marine Geared Turbine for Ship Propulsion. The turbine is of the Curtis high-speed type and has both "ahead" and "astern" elements. The gears are of the two-plane double-reduction type



General Electric Marine Turbine-generator Set which, with Induction Motors or Synchronous Motors, is Used for Electric Propulsion. The set is not made reversible as astern movement is obtained by reversing the motors

High-speed Turbine Drive of Merchant Ships*

By Eskil Berg

Turbine Engineering Department, General Electric Company

The modern steam turbine when considered simply as a prime mover has demonstrated its superiority in both efficiency and economy as compared with the reciprocating steam engine. In applying the turbine to ship propulsion, the problem confronting marine engineers today is that of selecting the method which will secure the highest overall efficiency for both the prime mover and propeller.

Three methods of application are as follows:

(1) The turbine directly connected to the propeller shaft. This method involves a serious sacrifice in the efficiency of both turbine and propeller, as the former must be operated at a speed greatly below its point of best economy and the latter at a speed greatly in excess of that which will give maximum propeller efficiency. This compromise method of direct connection between inherently high-speed and low-speed units, despite the attractive feature of its apparent simplicity, results in such low overall efficiency that, except in special cases, it is not now seriously considered as a feasible method by designing engineers.

(2) A gear train interposed between the turbine and the propeller. This method permits both the prime mover and the propeller to operate at efficient speeds, but involves the design and construction of single or multiple reduction gears which must withstand continuous operation under severe service conditions. It also necessitates a separate turbine element for reverse operation of the propeller.

(3) The substitution of what might be called an electrical gear in place of the mechanical gears of method (2). In this case the turbine is designed so as to secure the highest efficiency in the operation of an electric generator, and the driving motor, which is direct connected to the propeller, is in turn designed solely for that service. All reversing is done without reversing the turbine.

While the first method has practically been abandoned by marine engineers for commercial ships, the second and third methods have been applied to a considerable number of ships of various tonnage ratings and speeds, and the operating records which are now available make it possible to determine which methods should be applied when the service conditions are known.

* Abstract of a paper by the author at a joint meeting of the New York Sections of the A. I. E. E. and A.I.M.E., Jan. 28, 1921.

Advantages of Steam Turbine Over Reciprocating Engine

In a turbine, an expansion ratio of 400 to 1 can be obtained, the limit of expansion being entirely governed by the temperature of the cooling water; whereas, in a reciprocating engine, the limit lies in the size of the low-pressure cylinder. Marine engines generally have an expansion ratio of 15 to 1, or less. The net result is that the turbine realizes about 25 per cent more energy out of the steam than the reciprocating engine, and can do so more efficiently.

Turbine Speed

High-speed turbines are lighter, simpler and much more efficient than low-speed turbines. For a given horse power, there is just one speed (r.p.m.) for which the turbine can be made most efficient. If for any reason this speed is reduced, an inferior turbine is bound to result. The great majority of turbine ships now in operation have turbine speeds entirely too low for best economy. This condition has, no doubt, retarded the introduction of turbines for the propulsion of ships.

Propellers

Propellers are limited to low speed for high efficiency. Therefore, they should not be directly connected to turbines, although this has been done with great sacrifice of economy on some very fast and powerful passenger vessels, as well as on fast warships and destroyers.

The *Mauretania* is probably the best example of what can be done with this arrangement. She has four screws and develops about 69,000 h.p. with a propeller speed of 188 r.p.m. The turbine equipment consists of two high-pressure turbines and two low-pressure turbines, one turbine on each propeller shaft. This really makes two complete turbines, each having 34,500 h.p. To design the best turbine possible for this horse power, the speed should have been about 1400 r.p.m. instead of 188. The net result is that each turbine for the big *Mauretania* has an efficiency of only 62.75 per cent, which is much poorer than the Curtis turbines now being used on 2500-h.p. freighters with double-reduction gearing or with electric drive. Turbines of 35,000 h.p., running at 1500 r.p.m., are now in daily use, the efficiencies of which are over 80 per cent or 27.5 per cent better than the low-speed *Mauretania* turbines.

GEAR DRIVE

Single-reduction Gears

In every case, with the exception of destroyers and light scout cruisers, the writer has found that, in order to be able to use single-reduction gears, the turbine speeds have to be made too low to produce the best result, and also that a propeller speed has to be chosen which is too high for good performance.

Table 1 gives the approximate turbine horse powers and speeds required for the best efficiency. With turbines of the type most used for ship propulsion any reduction of these speeds will handicap the turbine. The table also shows that, even with double-reduction, the gears of types now used give turbine speeds which are lower than those suitable for best results.

TABLE 1

HORSE POWER	SPEED, R.P.M.
1000	8000
2000	5700
3000	5160
4000	4030
5000	3600
7000	3040
10000	2550
12000	2330
15000	2090
18000	1900
20000	1800

Efficiency of Gears

Most careful tests have been made by the General Electric Company to determine the efficiency of double-reduction ship gearing. These were made by connecting two ship gears together, with a turbine on one end and a high-speed generator on the other. After these tests had been run, the gears were removed and the turbine was connected directly to the same generator. A comparison gave the gear losses of the two ship gears and, as these losses were twice that of one gear, they could be accurately measured. The result of these tests is given in Fig. 1. By present standards, 1540 h.p. on this curve corresponds to what would be considered conservative tooth pressure for long life of the gears. The efficiency at this point is 94.5 per cent.

Tests made in similar manner on single-reduction gears, but of smaller capacity, indicate that, for a conservative design and for such speeds as would generally be required in ship work, an efficiency of 97 to 97.5 per cent may be expected. This gain in efficiency over double-reduction is, however, lost in the turbine as this machine must be designed for lower speed.

The result of all the gear tests made shows that: low peripheral speed and high tooth pressure give the best efficiency, and that the efficiency falls off rather rapidly with increased speed and lower tooth pressure.

Loss in Reversing Turbine

The friction loss of the reversing turbine depends upon the design and the degree of reversing torque desired. Tests have been made in Schenectady on the reversing turbine of a 2500-h.p. ship. Its reversing element gives full-load torque at standstill, has two stages, and is specially proportioned to give low rotation loss.

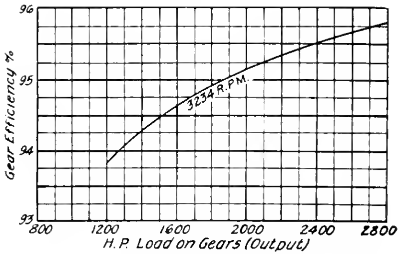


Fig. 1. Efficiency Curve of a Double-reduction Gear

The tests were made by driving the reversing wheels in a vacuum with a high-speed synchronous motor. With 28 inches vacuum and with highly superheated steam in the casing (about 300 deg. superheat) this loss amounted to 28 h.p. In actual operation one of the reversing wheels runs in contact with steam which is kept in motion by the ahead turbine and which carries about 12 to 15 per cent moisture. This condition greatly increases the rotation loss and a conservative estimate of the rotation loss of the reversing wheels during actual operation would be 44 h.p. or 1.76 per cent. If for any reason the vacuum should be impaired, the loss increases practically as the absolute back pressure.

Heat Variation While Reversing

In the act of reversal, work is done upon the steam before it can begin to do work, and this work all goes into superheat. The work comes from the motion against the force of the steam, this motion being the result of the momentum of the parts and of the effect of water to keep the propeller going in its original direction. That this superheating, under some conditions, reaches a very high temperature is now well known.

If for any reason backing is done for any length of time, these same heat variations occur in the main forward turbine when an order for "ahead" is received.

Transmission Efficiency of Gears

The efficiency of conservatively designed double-reduction gearing is about 94½ per cent, and the loss incident to the reversing turbine is about 1.76 per cent, making a total loss of 7.26 per cent. Besides, there is a loss in efficiency of the turbine itself due to the necessity of larger clearances and the fact that the reversing elements make the turbine longer, which means larger shaft and greater leakage loss between diaphragms, as well as increased packing and bearing losses. To this should be added the power taken by the various oil pumps required for the lubricating system.

If the turbine for any reason is split up into two casings (high and low-pressure), there are additional packing losses as well as loss during transfer of steam from one turbine to the other. This latter loss is large and may amount to 2 or 3 per cent.

Life of Gears

During the war several hundred geared turbine ships were built. Some were of the single-reduction type but the majority, in order to use a turbine of better efficiency, were equipped with double reduction gearing.

A few of these gears have given excellent results, particularly those employed on war ships where maximum power is used only on rare occasions. In the merchant marine there are also quite a number of geared turbine ships giving successful operation. There has, however, been a great number of very serious gear failures. In many cases similar equipment in similar ships would give entirely different results in regard to the life of the gears.

With the experience and knowledge now acquired there is no doubt that some of the early gears were entirely too small to stand the great fluctuating load which takes place due to the variations of propeller torque in heavy seaway, as well as the excessive load on the gears caused by any misalignment due to distortion of the hull in heavy seaway.

Variation of Propeller Torque

A torsion spring coupling was applied to the *Jebsen* when running in ballast. The average horse power was 2000 and the propeller speed 78 r.p.m. In a moderate sea, with the ship pitching only four degrees, the load varied every seven seconds from 0 to 3500 h.p. This variation of horse power no doubt is caused by the high flywheel effect of the rotating parts of the turbine and gears, which prevents the slowing down or speeding up of the propeller to follow the large load variation on the propeller while in heavy seaway.

Knowing the inertia of the turbine and the gears, a load variation such as shown in Fig. 2 would indicate that the propeller speed varied from 74 to 82 r.p.m. with a mean of 78 r.p.m. every seven seconds.

Distortion

On a 2500-h.p. gear casing which measures about 10 by 11 ft., a light thrust beam recently was pivoted and multiplying devices arranged by which any movement of the corner of the gear casing with relation to the ends of the arm could be noted. Readings were taken under different conditions of sea and wind. Under one condition of heavy quartering sea, the starboard after corner of the gear casing had an apparent movement of which the amplitude of relative motion showed 5/100 of an inch. At times the relative motion was somewhat of a vibratory character, being affected by the tremors of the ship.

While these relative movements may, in part, have been caused by the springing effect of the gear cover which supported the arm, nevertheless the movement must have affected the alignment and load distribution of the gears and may account for the large excess pressures which seem to be indicated by the performances of many ship gears.

ELECTRIC DRIVE

Electric transmission affords a simple and practical means of speed reduction in almost any ratio which may be desired.

Reversal

It affords means of reversal by simple change of electrical connections without changing the direction of rotation of the turbine.

Reversing Torque

Any desired reversing torque up to the full power of the turbine can be obtained without affecting the efficiency of the equipment in the forward direction.

Power Measurement

Electric drive makes possible the obtaining of accurate data, either by instantaneous reading or by recording instruments, of the load on the propeller shaft under various conditions of sea and wind. It also gives means by which the total horse-power hours can be recorded during any given time or cruise. By comparing these data with the fuel consumption, a direct check can be obtained as to economy.

Interchangeability

Electric drive makes possible the use of a plurality of generating units so that damage to one or more parts will not disable the vessel.

Economy at Reduced Speed

In many of the fast passenger vessels it may be desirable to run at lower speed during certain seasons of the year. With electric drive, where two or more generating units are used, one or more of these can be shut down with all its auxiliaries and an economy can be obtained at reduced speed almost equal to that at maximum speed.

High Steam Pressure and Superheat

With electric drive, full advantage can be taken of the increased economy afforded by high steam pressure and superheat since the turbine itself is never reversed.

Design of Turbine

The turbine for electric transmission can be built for better efficiency. Since no reversing wheels are required, the turbine becomes shorter, which gives a smaller shaft, less packing leakage and less weight which reduces bearing loss. Smaller clearances can be used. The turbine is built in one casing. Thus the packing and other losses incident to splitting the turbine up into two or more casings are avoided.

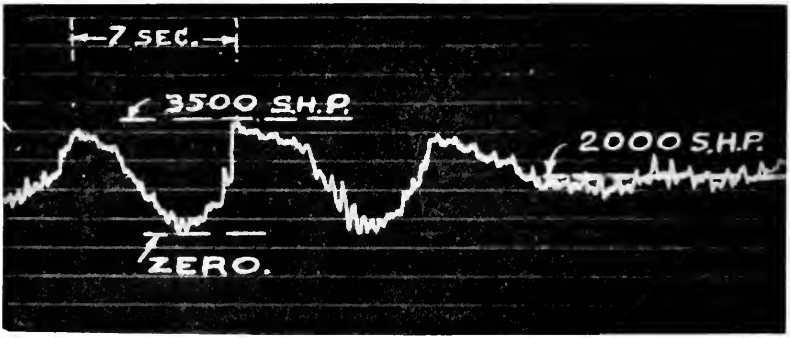


Fig. 2. Record from Torsion Spring Coupling on *Jebsen* in Ballast in a Moderately Rough Sea. Part of the smaller fluctuations resulted from an untrue collar in the instrument; otherwise the record is correct

Location of Apparatus

Electric drive in many cases may afford another important advantage; namely, that the generating unit, or units, can be located in any convenient place near the boilers, with their condensers mounted directly under the turbine, thus reducing the steam and exhaust piping to a minimum and diminishing the chances of air leaks so detrimental to good vacuum conditions. The propelling motors can be placed near the propellers, thus eliminating long, expensive shafting, and the incident bearing losses and shaft alleys, thus saving hold space and making cargo handling very much more convenient.

Auxiliaries

With electric drive, a great many of the main auxiliaries can advantageously be electrically driven and this affords a large saving in fuel. In case of any trouble with any of the main propelling machinery, or condensing equipment, arrangements can very easily be made by which the ship can be propelled at reduced speed from the auxiliary power circuit. This feature should be valuable for single-screw vessels.

Reliability

The simplicity and reliability of the electric generator and motor are too well known to need further comment. It is doubtful if anything so reliable has ever before been used to drive a ship. The Navy Department, after most careful comparative study, has adopted electric propulsion for all of our large naval vessels. The Shipping Board is, at the present time, replacing twelve 3000-h.p. geared ship equipments with electric drive. The first ship, the *Eclipse*, of about 11,900 tons, has successfully finished her trial trip and is now on her way to the East Indies. On her trip from New York to Gibraltar she "eclipsed" the record of similar ships by two days (about 20 per cent) and reported everything running most satisfactorily.

Weight

It is very difficult to give a direct comparison of weights between electric drive and geared drive as all depends upon the type and service of the vessels. For destroyers, light high-power cruisers, or fast pleasure yachts, the geared turbine is very much lighter. In high-speed passenger vessels, the turbine and the gears themselves may be slightly lighter than electric drive but, when the steam and exhaust piping and oiling system are taken into account, the difference in weight is so very slight that it cannot be of any consequence.

The weight of the electric propelling equipment of the Collier *Jupiter* (7000 h.p., twin screw) is 156 tons; the weight of the geared equipment on the *Neptune*, sister ship, is 150 tons. When the piping, oiling system, etc., are added the *Jupiter* equipment is the lighter.

In low-speed freighters of about 2500 or 3000 h.p., a conservative gear design of double-reduction type with single-unit turbine, as built by the General Electric Company, weighs (including the oiling system) about nine tons less than electric drive. If, however, with electric drive the motors are put aft, where they really belong, the saving in weight of shaft, bearing supports, shaft alleys, etc., makes the electric drive very much lighter.

As compared with reciprocating engines, electric drive weighs only about 40 per cent.

Cost

While electric drive may in itself cost slightly more than geared turbine drive, the saving incident to piping, foundations, shafting, shaft alleys, oiling system, etc., makes it in many cases by far the cheaper.

Efficiency of Transmission with Electric Drive

The propelling equipment of the *Cuba* (17-knot, 3000-s.h.p., 100-r.p.m. passenger boat) had a most complete test at the factory. The motor showed an efficiency of 95.65 per cent, including excitation, and the generator gave an efficiency of 96.3 per cent. The transmission loss is therefore 7.89 per cent. The cable loss is about 0.04 per cent., making a total loss of 7.93 per cent. This figure compares with gear transmission efficiency of 7.26 per cent, the difference being only 67/100 of one per cent in favor of gearing. With increasing horse power, the efficiency of the generators and motors becomes higher and, in machinery designed for certain high power ships, the efficiency reaches 94 per cent.

Superheat

The introduction of high-speed turbines driving electric generators, with high degrees of superheat, has enormously reduced the cost of power for all purposes on shore. In fact, no power plant could today afford to run without superheat. On board ships, improvement in economy in the engine and boiler rooms is several times as important as in power stations, for ships must not only buy their fuel at prices prevailing in various parts of the world, but must carry it for long distances, thus displacing useful freight carrying capacity. While the use of high degrees of superheat on our ships has made little headway up to the present time, the introduction of electric drive should greatly hasten this great advance toward fuel economy.

CONCLUSIONS

In merchant ships each individual case must be studied, and here the questions of service, economy, reliability, weight, and cost must be taken into consideration.

For fast passenger liners electric drive has an advantage. The transmission efficiency can be made practically equal to that of a conservatively proportioned double-reduction gear. It has also the advantage that the turbine can be made more efficient.

If two generating units are used, one unit will propel the vessel at about three-quarters speed with only a slight sacrifice in economy. Noise, so objectionable in passenger vessels, is practically eliminated with electric drive.

In moderate power twin-screw ships of about 6000 h.p., electric drive has a decided advantage in economy, weight, and price if one turbine-generator unit is used to drive both propellers. In case this unit, or any of its auxiliaries should become disabled, a simple arrangement can easily be made by which the ship can be run at low speed from the auxiliary generating unit which normally drives the electric auxiliaries. On the other hand, if two generating units are used, the equipment becomes slightly less efficient, the weight and cost also go up considerably, and the comparison then becomes similar to that of a 3000-h.p. single-screw freighter.

For low-speed single-screw freighters of about 2500 to 3000 h.p., geared-turbine drive is somewhat the lighter. The actual transmission efficiency of the gears is also better. However, when the losses of the reversing turbine, the power taken by the oiling system, the packing losses, as well as the leakage of steam due to larger clearances are taken into consideration, the transmission efficiency is practically equal or if anything in favor of electric drive. Also, if the motor is located aft, doing away with long shafting and its expensive bearings, supports, and shaft alleys, the electric drive is the lighter, cheaper and more economical, as well as the more reliable. With the main auxiliaries driven electrically, the ship can by a very simple arrangement be run to port by power supplied from the auxiliary generators should the main propelling machinery or its auxiliaries become disabled.

In freighters of 1500 h.p. or less, geared turbines are lighter and cheaper than electric drive. As the power is small, a gear can be designed which is less affected by sudden load variation or misalignment caused by springing of the hull.

Up to October 1, 1920, General Electric marine geared equipments have been installed in 291 merchant ships, and these vessels have steamed a total of 16,780,000 ship-miles.

The electric propelling equipments which have been built by the General Electric Company, together with those now under construction in its factories, are as follows:

For the Navy		H.P.		H.P.
1 collier		7,160;	total	7,160
4 battleships	each	32,000;	total	128,000
2 battleships	each	60,000;	total	120,000
4 battle cruisers	each	180,000;	total	720,000
Total				975,160

For the Merchant Marine	H.P.		H.P.
12 freighters	3,000;	total	36,000
4 coast guard cutters	2,600;	total	10,400
1 fruit steamer	3,000;	total	3,000
1 express passenger vessel	3,000;	total	3,000
Total			52,400

Merchant Ship Propulsion Gears

By A. A. Ross

Gear Division, Turbine Engineering Department

The use of gears to transmit power and regulate the speed between the driver and driven elements has been in vogue for years, but unfortunately to most mechanics in the past a gear was a gear and nothing more, sometimes barely that. In recent years, however, there has been a remarkable advancement in the development of the gear art; and if a person will but pause for a moment to examine the many different types of machines with which he comes in contact during his every day walks of life, he will find that the majority are dependent upon a gear train, either single, double, or triple reduction for the successful control and operation of their most vital parts. Now if we were to delve into the records of each of these successful gear applications, be it automotive, industrial, or railway, we would find the early pages filled with discouraging failures, but on the final page we would note that the designing engineer had printed the word "Success" with the following inscription—"From Actual Service Observations."

The application of gears to the propulsion of merchant ships in this country has been no exception to the rule. Records show failures so serious that many engineers recommended the substitution of combustion engine drive, while others turned back to reciprocating steam engines. Five years of service experience has culminated in the development of a thoroughly satisfactory double reduction gear for ship propulsion. This article constitutes a summary of the various features in the design and construction of this type of gear which service experience has shown to be necessary to insure economy and long life.

These features are embodied in the 1920 two-plane double reduction gear as shown in Fig. 4 and briefly outlined in the following description.

Fig. 1. High-speed Gear

DOUBLE REDUCTION GEARS

Double reduction gears for merchant ship propulsion are now quite generally recognized as being the most suitable intermediate between the turbine and propeller for 10 to 12-knot cargo boats and tankers of approximately 8,000 to 10,000 deadweight tons and requiring 2500 to 3000 s.h.p., 3300 to 90 r.p.m. Those manufactured by the General Electric Company have been built in two types; viz: the one-plane type, in which the turbine shaft and the propeller shaft lie in the same plane, and the two-plane type, in which the

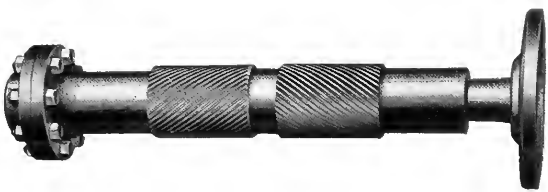


Fig. 2. High-speed Pinion

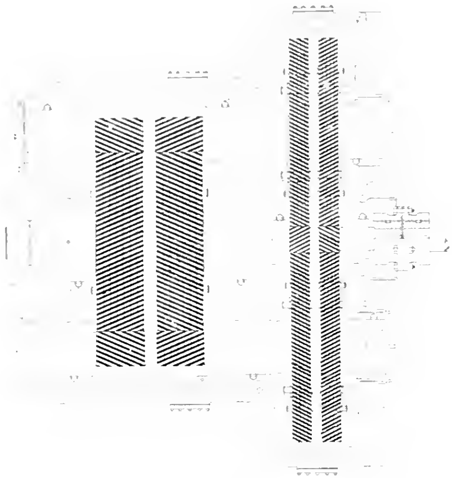


Fig. 3. 1914 Design Two-plane Type Double Reduction Marine Gear

turbine shaft lies in a plane above that of the propeller shaft.

The first sets built were of the two-plane type. One set was installed in 1915, two more in 1916, and three in 1917, and had the General Electric Company held to this design and incorporated in it the features which actual service experience found necessary, success would have been attained earlier; but in 1916 when the war brought on the demand for ships and machinery to propel them, the one-plane type, a more simplified design, which would better meet rapid production requirements, was developed, because when the United States entered the great war it was recognized that the effectiveness of our armies would depend on how rapidly we could build and equip merchant ships. Hulls could be built faster than propulsion machinery. Although orders had been placed for a large number of ships requiring double-reduction marine geared turbines, the only ones in actual service at that time were some fourteen sets built by the General Electric Co. These were equally divided between the one and the two-plane types and both types up to that time were operating satisfactorily; but as production was the paramount feature the one-plane type became the war emergency

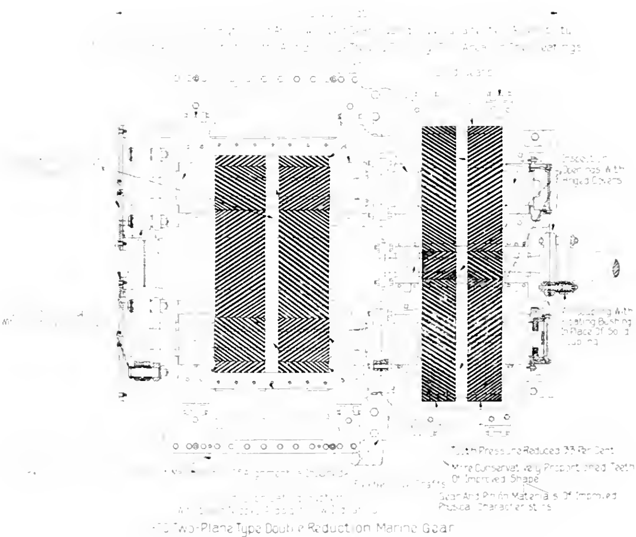


Fig. 4. 1920 Design Two-plane Type Double Reduction Marine Gear

unit, and as such did reasonably well considering rush production and war time materials and labor. On the other hand, the large number rushed into service gave in two years the operating experience which, under ordinary circumstances, it would have taken ten years to obtain.

With the completion of war rush orders the two-plane type was adopted as best suited to meet the operator's requirements under the post-war conditions for the following reasons:

First: Each high and low-speed gear train must be aligned on board ship so as to obtain and maintain the proper tooth contact. This is difficult where both high and low-speed elements are enclosed in the same housing as in the one-plane type. In the two-plane type, each element is enclosed in a separate casing, permitting of a more rigid casing which is easier to align and in which proper tooth contact is maintained.

Second: Tests on board ship under various weather conditions showed high momentary overloads, averaging 50 per cent overload for 3½ seconds duration. Hence, it was found necessary to reduce the tooth loads per inch of face from approximately 500 and 1100 lb. on the high and low-speed elements of the original equipments to approximately 300 and 600 lb. This reduction can be accomplished by increasing the gear faces, or by increasing their diameters or by both. An increase in the already rather wide gear faces of the one-plane type not only results in manufacturing and tooth contact difficulties but will require the installation of the objectionable middle bearing in the low-speed pinions to overcome bending. On the other hand, it will be noted by referring to Fig. 3 that the centers of the low-speed pinions and high-speed gears are diametrically opposite and on the horizontal plane of the center of the low-speed gear. Hence, an increase in the diameter of the low-speed gears will also necessitate an increase in the high-speed gears, an increase in the gear centers and an increase of the athwartship dimensions of the casing. This is a step in the wrong direction, for the high-speed element should be as small as possible and the athwartship dimensions of the frame should be kept within reasonable limits, because a wide casing is more susceptible to the weaving of the ship which has a detrimental effect on the teeth in contact.

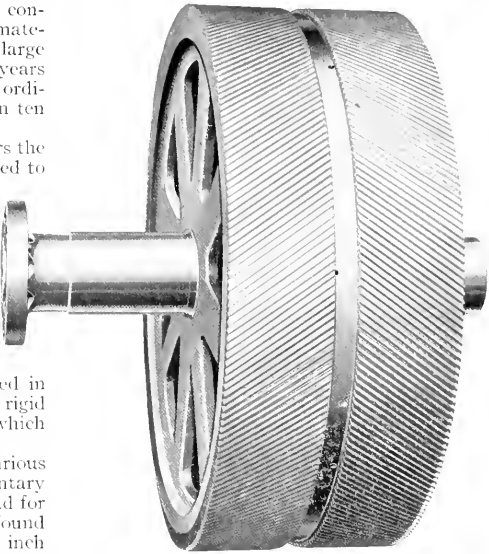


Fig. 5. Low-speed Gear

In the two-plane type, Fig. 4, the low-speed pinions mesh into the low-speed gear near its top. Therefore the diameter of the low-speed gears can be increased without increasing the

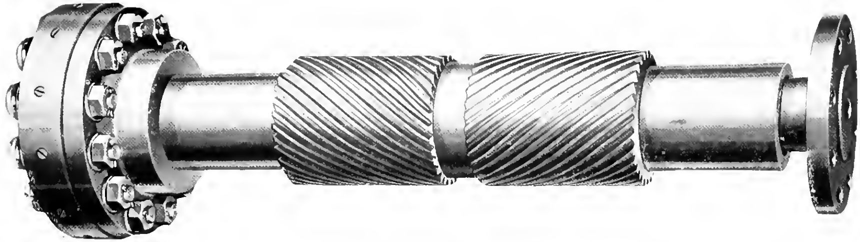


Fig 6. Low-speed Pinion

diameters of the high-speed gears. That is, the tooth load reduction is obtained by a combination free from the objections above mentioned.

Third: Vibrograph records taken on board ship at sea showed very heavy vertical vibrations in the propeller shaft; and, with the low-speed gear shaft coupled rigidly to it, the vibrations are transmitted to the low-speed gear. While there is no direct evidence that these vibrations are the cause of distress between the low-speed gear and pinion teeth, many low-speed pinions in service show evidence of peening action. By comparing Figs. 3 and 4, it will be appreciated that if these vibrations have any effect on the teeth in contact, they will be much more disastrous in the one-plane type where the blows are direct: whereas in the two-plane type, with the pinions on top of the gear, the blows are in a glancing or sliding direction.

High and Low-speed Gears

The gears in both high and low-speed elements are of the solid herringbone type. Each gear consists of a cast iron hub, which carries two high-carbon heat-treated forged steel tires shrunk on its periphery to form the helices of the gear. Each gear is pressed and keyed on its shaft which is supported by two babbitt-lined bearings.

High and Low-speed Pinions

Each high and low-speed pinion is made of high-carbon heat-treated forged steel, and as will be noted in Figs. 2 and 6, is made in the form of a quill which offers the best possible section for uniform heat treatment. Each pinion is supported by two babbitt-lined bearings.

Arrangement

Referring again to Fig. 4, it will be noted that the turbine shaft is connected to the flexible high-speed shaft by a pin coupling, Fig. 8. This flexible shaft extends through the bore of the high-speed pinion and is connected to it on its aft end by a solid coupling

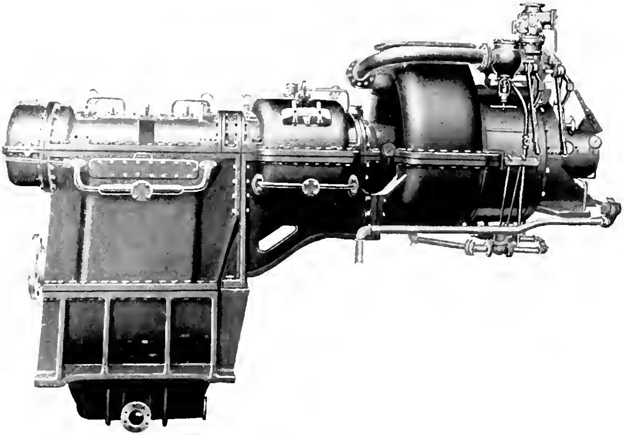


Fig. 7. Two-plane Type Marine Geared Turbine—Starboard or Operating Side

The driving high-speed pinion meshes into the teeth of the two high-speed gears on opposite sides of its horizontal diameter. The aft end of each high-speed gear shaft has a forged-on flanged half coupling, which bolts to a similar coupling on the low-speed flexible drive shaft. These shafts in turn extend aft through the low-speed quill pinions and are connected to them by pin couplings, Fig. 9.

It will be noted, therefore, that this is a very compact flexible arrangement and permits fore and aft movement of the low-speed pinions relative to the low-speed gear without interfering with the fore and aft movement of the high-speed train, or vice versa the high-speed train can move fore and aft without interfering with the low-speed train.

The low-speed gear shaft is coupled rigidly to the propeller shaft. Hence the low-speed gear is limited in its fore and aft movement by the ship's thrust. Therefore the pin couplings with floating bushings will permit the low-speed pinions to trail the low-speed gear. On the forward end of the starboard high-speed gear shaft is a button type end-thrust bearing which limits the fore and aft movement of this gear. The floating bushings of the high-speed pin coupling will permit the high-speed pinion and port high-speed gear to trail with the starboard high-speed gear.

High-speed Gear Casing

The high-speed gear casing is of rigid design, divided horizontally at the center of the bearings into two main parts and made of high grade cast iron (Fig. 7).

ow-speed Gear Casing

The low-speed gear casing is split on two horizontal planes, one through the center of the low-speed gear bearings, the other through the center of the low-speed pinion bearings, thereby dividing the casing into three sections. The complete casing is made of high grade cast iron, heavily flanged, and when

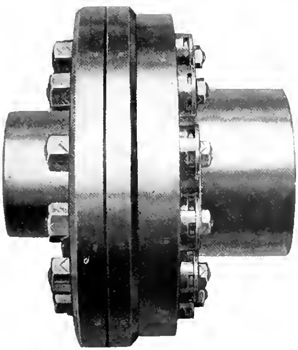


Fig. 8. Assembled High-speed Pin Coupling

bolted together forms an extremely rigid compact element (Fig. 7).

Lubrication

The high and low-speed gears and bearings are supplied with oil from separate double-inlet header lubrication systems. The lubricant is delivered from the ship's main lubrication system to cast pipe connections on both the starboard and port sides which lead to the cast-in supply pipes directly under the bearings of each element extending athwart-

Fig. 9. Assembled Low-speed Pin Coupling

ships through the casings. This arrangement insures a perfectly balanced system.

The gears and pinions are lubricated by a series of specially designed spoon nozzles which discharge a sheet of oil directly into the mesh. Each spoon nozzle is provided with a sight flow indicator which insures the maximum possible protection against stoppage of oil to the gears

Carefully calibrated oil gauges are located in the oil line to the bearings to insure that proper oil pressure is maintained.

The oil for the lubrication of the pins and bushings of the pin couplings is supplied through individual internal passages.

Teeth

The high-speed element is provided with 4-pitch helical angle teeth (Fig. 10); and the low-speed element with $2\frac{1}{2}$-pitch helical angle teeth (Fig. 11).

Data obtained from exhaustive factory tests and observations of actual service conditions to determine the relative values of different tooth shapes for carrying load prove the superiority of the type of teeth adopted for the 1920 design of double reduction gears.

Those who are not as familiar with the herringbone gear or helical type tooth as with the spur gear, which is the common type of tooth met with in every-day practice, will no doubt ask why the herringbone gear is used in ship propulsion.

The high-speed of the turbine results in a very high pitch line velocity. This requires a type of tooth which will insure that the driving pinion will transmit its torque to its companion driven gear in a smooth continuous angular motion.

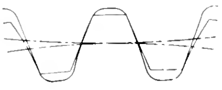


Fig. 10. High-speed 4-pitch, 35-degree Helical Angle Teeth

The helical type tooth in the herringbone gear, as will be noted in Figs. 5 and 6, spiral the circumferences of the gear and pinion. Hence, there are always one or more points in contact at the pitch line within the arc of action. In the spur-tooth gear, contact at the pitch line takes place only once as each tooth passes through the arc of action, and it is claimed by authorities on the subject that the transfer of the load on the spur tooth, beginning below the pitch line as the driving tooth engages its driven companion and traveling to the top of the tooth as they disengage, causes a change in the angular velocity which results in vibration and noise at high speed; whereas on the helical type tooth, this change in angular velocity is prevented by the continuous contact at the pitch line.

The writer, however, is not entirely in accord with this theory and believes that future developments will prove that spur gears with teeth correctly proportioned for the ratio and accurately cut can be operated satisfactorily at pitch line velocities heretofore believed impossible, and also that on the low-speed element of double reduction ship propulsion gears, where the pitch line velocity is not excessive, the long-life low-speed gear of the future will be of the spur

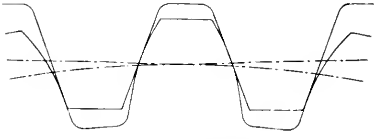


Fig. 11. Low-speed $2\frac{1}{2}$-pitch, 35-degree Helical Angle Teeth

type, hardened and ground after the teeth have been cut.

Bearings

The bearings are of the cylindrical type having cast iron shells lined with the best quality of babbitt securely anchored by dovetailed circumferential and axial grooves.

Inspection Facilities

In order to facilitate inspections, hinged covers are provided over the pinions, gears, pin couplings, and oil nozzles on both the high and low-speed elements.

Alternating-current Generators for Ship Propulsion

By E. H. Freiburghouse

Alternating-current Turbine-generator Engineering Department, General Electric Company

The mechanical and electrical designs of the steam turbine driven alternators installed on the Collier *Jupiter* and the U. S. battleship *New Mexico* have proved reliable and successful during several years of service. The design and operating characteristics of these generators have been previously described.*

Fig. 1 is the photograph of a partially assembled three-phase alternating-current generator of the type now being built for cargo boats, which will supply power to motors of either the induction or synchronous types. Still another

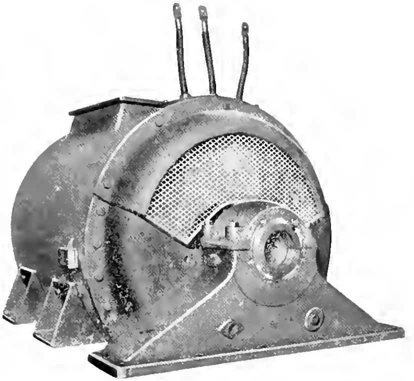


Fig. 1. Partial Assembly of Three-phase Alternating-current Generator for Electric Propulsion of Cargo Boats

and later design, in which the generator end bearing is carried by the end shield, is shown in the sectionalized view of Fig. 3. The *Eclipse*, a 12,000-ton cargo boat just recently put into service, is furnished with one turbine alternator wound three-phase, having two poles, and normally rated to generate 2300 volts, 3380 kv-a. at 0.7 p-f., and 3000 r.p.m. As the power-factor indicates, this boat is driven by an induction motor. At present, the 3000-ton coast steamship *Cuba* is the only ship yet in service driven by a synchronous motor. In this boat, one two-pole alternator having a normal rating of 2350 kw., 1.0 p-f., 3000 r.p.m., 1150 volts, supplies the power.

*"Electrical Equipment for the U. S. Collier *Jupiter*," by Eskil Berg, General Electric Review, Aug., 1912.
"The *New Mexico's* Generator," by C. S. Raymond, General Electric Review, April, 1919.

It was a comparatively simple matter to adapt to marine service the alternator developed for central power stations.

The ventilation of the generators on the *Jupiter* and the *New Mexico*, also of the smaller alternators now being installed upon cargo boats, has been obtained in much the same manner as for land sets.

As the alternator is the only source of electrical power for bringing the boat to port, it is natural that far greater importance should be attached to its reliability for continuity

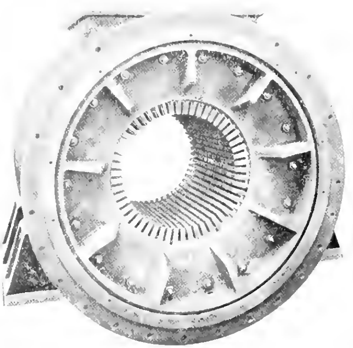


Fig. 2. Assembly of Armature Structure Showing Open Slot Laminations which Permit of the Use of Form-wound Coils

of service than to any other feature. This is especially true if the boat has but one generator. Reliability of a low-potential alternator as to continuity of service depends upon freedom from mechanical distortion of its coils and consequently of the insulation. In service, instantaneous short circuits of the armature are accidental and very infrequent. Although the mechanical stresses between phase belts are proportional to the square of the short-circuit armature currents, and approximately one hundred times normal, nevertheless numerous single and three-phase instantaneous short-circuit tests recently made in the factory upon one of the cargo boat type alternators caused no distortion of the armature winding.

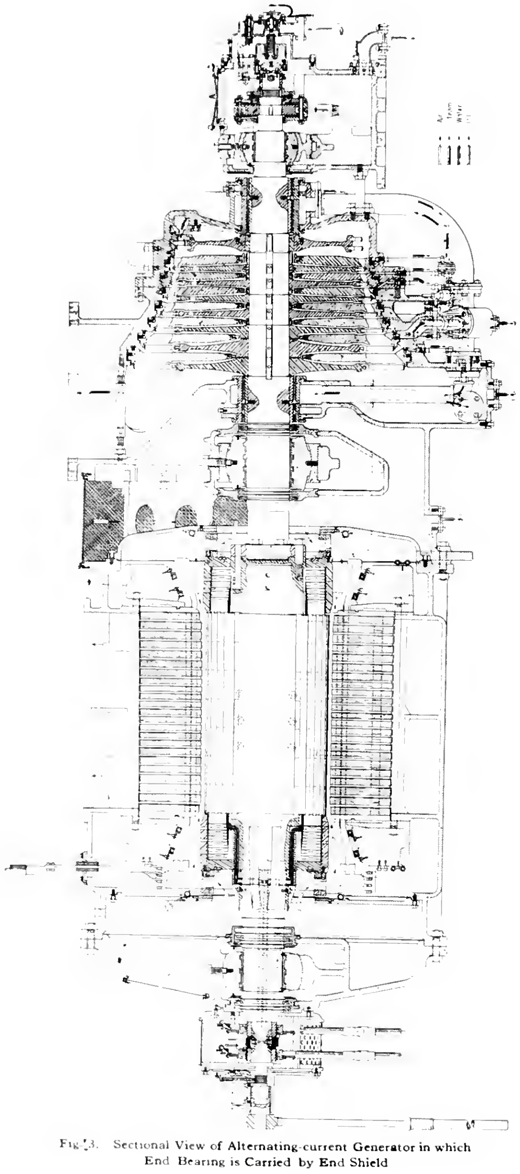


Fig. 3. Sectional View of Alternating-current Generator in which End Bearing is Carried by End Shield

Stator Winding

The armature punchings as seen in Fig. 2 have open slots which permit the use of form-wound coils or bars which are insulated before assembly in the core. The stator coils are made up of one or more turns, each turn consisting of many rectangular copper strips in multiple, insulated from each other throughout the coil for the prevention of loss by eddy currents. The armature coils or bars are insulated first with mica tape, impregnated after application by a vacuum process with moisture-proof compound, then with layers of black varnished cloth of highly moisture-repellent characteristics. The surface of the coil is given five coats of moisture-proof varnish, each coat of which is baked until dry. A tough slot armor of horn fibre protects the insulation of the coil from mechanical injury in the slot. As seen in Figs. 4 and 5, the end portions of the armaature winding are secured to, and insulated from, steel binding bands which prevent distortion of the coils and damage to their insulation during any sudden short circuit.

Protection against sustained short circuits or unbalanced loads is obtained by means of relay equipment which will cause the contactors of the armature and field circuits to open.

Rotor

The revolving field, Fig. 6, has a one-piece, heat-treated, solid-forged steel shaft which serves also as yoke and core of the field portion of the magnetic circuit. Radial slots are milled in the body portion of the shaft and these carry the distributed field winding of several coils per pole. During the past ten years turbine alternators have been built by the General Electric Co. having one-piece solid-forged shafts, not one of which has failed or shown any sign of failure in test or service while operating within the guaranteed speed limits.

Rotor Winding

The field coils are formed from copper strips wound edgewise. After insulation of the turns with mica tape they are fed into the slot.

turn after turn. A combination armor of tough heat-resisting insulation protects the complete coil from the slot. The coils are held in the slots by steel and non-magnetic alloy wedges.

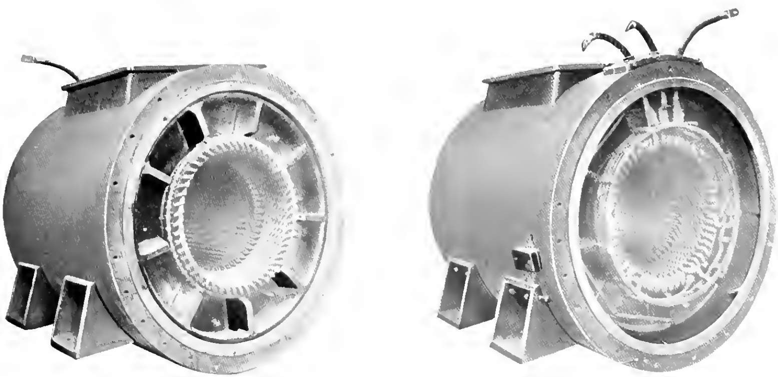
Beyond the slots, the end portions of the coils are insulated, blocked, and held in place by broad nickel-steel retaining rings which are shrunk onto projecting lugs of the rotor body and over the centering rings at each outer end.

As a result of the high rotary speeds employed and the unequal expansion of copper and steel with change in temperature, distortion and abrasion of insulation over the end portions of the field coil as a whole might be expected. By the scheme of blocking employed and the thorough insulation obtained between copper and supports, relatively little trouble of this nature has occurred on land type turbine alternators. The rotors of the *Jupiter* and *New Mexico* have never caused any trouble.

Light, broad, metallic saddles are now employed, made to conform with all the curvatures of the end portions of each field coil. When blocked, these saddles hold in place the coil insulation about the coil and assume any abrasion which may be caused by the relative movement of the coil and the retaining ring.

A maximum power output of given power-factor is obtained from any alternator at constant speed and field excitation when the percentage changes of armature voltage and current are equal for change in load. As contracted for central power stations on land, it is understood that the maximum continuous output of a turbine-driven alternator corresponds to that of certain limiting temperatures of both field and armature windings. This may or may not correspond with the maximum electrical power output at which the percentage changes of armature voltage and current are equal; nevertheless it may be inferred that the percentage change of voltage should not be greater than that of current, otherwise the generator would be unstable at its rated load.

Referring to the field characteristics, shown in Fig. 7, of the generator and motor installed on the *Cuba* it is seen that for normal field excitation of 136 amperes on the generator and 208 amperes on the motor an increase of close to one-third torque at normal speed may occur before the motor will drop out of step. In other words, this alternator and motor have been so designed that a momentary load of one and one-third times normal may be carried without change of field excitation. If, however, momentary overloads are expected, as in a rough sea, increased excitation may be impressed upon the alternator when driving induction motors or upon both alternator and synchronous motor, thereby maintaining higher armature voltage and less armature current for the same power output. Again referring to Fig. 7, it is seen that if a field excitation of 160 amperes is held on the alternator and the proper excitation upon the synchronous motor to obtain unity power-factor at the normal load of 2350 kw., the momentary



Figs. 4 and 5. End Views of Generator of Fig. 1, Showing Form-wound Coils Completely Assembled. Note the method of supporting end windings by steel binding bands

torque may be increased approximately 70 per cent before the motor will drop out of step. Decreased efficiency of the alternator and motor by increased core loss and excitation, also the limiting temperature of the field insulation, place a limit upon such gain in continuous margin of power.

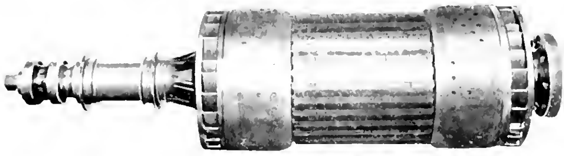


Fig. 6. Revolving Field for the Generator of Fig. 1

Temperature Indicating Devices

It has been shown that the field excitation which may be given momentarily determines the momentary overloads; however, the maximum continuous load which may be carried on an alternator without undue reduction of the life of the winding is based upon the maximum temperature attained by any part of the insulation. As is customary in land practice, standard temperature coils are placed in the armatures of alternators for marine service between the top and bottom armature bars or coils, also between the coils and core at accessible points which are subjected to the highest temperatures. The temperature coil indicating instrument used in connection with these coils enables the operator to know at all times the temperature of the armature winding.

Because of the wide variation in operating conditions, especially speed and excitation which determine the heating of the rotor winding, it is necessary to know the field temperature. Temperature coils are impractical in the rotor, consequently, a special temperature instrument* is employed. The calibrated deflection of this meter is based upon the change in resistance of the given field winding. Knowing the field temperature, the operator is safely guided in determining the maximum output.

Fire Extinguishing and Heating Coils

Brass or copper tubing secured to the inner end-shields of the alternator has a number of holes drilled in it through which steam may be discharg d over the windings in case of fire. After closing a damper in the outlet air duct, steam supplied in sufficient quantities will extinguish a fire in the insulation almost instantaneously even though the fire is under the heavy draft utilized for the ventilation of turbine alternators. Experimentally, it has been definitely shown that the closure of the outlet air damper is far more effective when using steam for extinguishing the flames than the closure of a damper in an inlet air duct.

To prevent condensation of moisture upon the windings of the alternator when not in service, heating coils are provided within the generator end-shields. With these protective devices and reasonable care in operation, no greater difficulty should be experienced than with an alternator on land.

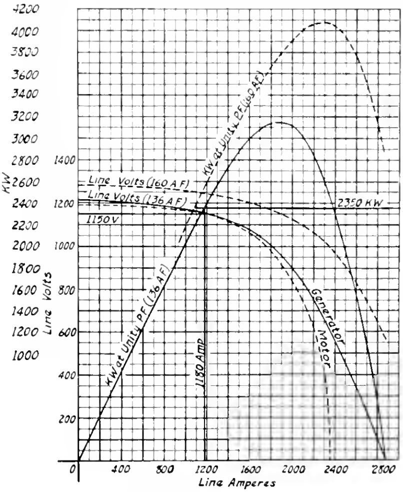


Fig. 7. Characteristics of the Generator and Synchronous Motor of the Steamship *Cuba*

* A complete description of this instrument is given in A. H. Mittag's article in this issue.

Synchronous Motors for Ship Propulsion

By E. S. Henningsen

Alternating-current Engineering Department, General Electric Company

Although self-starting synchronous motors have been in general use for over twenty-five years, it is only within recent years that they have been used to large extent in practically all lines of industry. Originally designed only to drive motor-generator sets and for similar classes of service requiring very little starting torque, they have gradually been developed to the point where they are employed very generally to drive compressors, pumps, blowers, tin and copper rolls, flour, rubber, and cement mills, and for many other classes of service requiring high starting and pull-in torque. The latest application of this type of motor is for ship propulsion.

Since the synchronous motor must operate first as an induction motor during the operation of starting and coming up to speed, and then as a synchronous motor after the application of excitation to the field, the design must be a combination of the two types. Some of the factors involved in the design are such as to be advantageous to one type but disadvantageous to the other. For example, a small air gap is desirable in an induction motor, but means low breakout capacity in a synchronous machine; deep pole tips are required to give space for a heavy amortisseur winding, but carried to extremes cause high field leakage and an increase in excitation as a synchronous machine, etc. It is possible, however, to compromise these various factors and to obtain a motor which combines high efficiency and breakout capacity with very good torque characteristics.

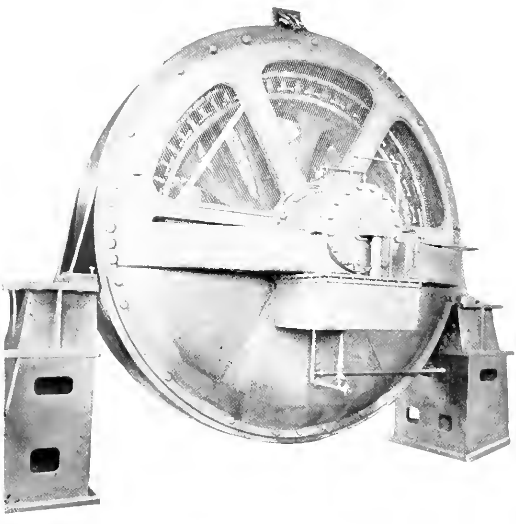


Fig. 1. 3000-h.p. Synchronous Motor of the Steamship *Cuba*

Motors and generators designed for ship propulsion differ considerably both mechanically and electrically from those intended for land use. In shore stations the voltage and frequency are constant, on shipboard both are variable since speed control is obtained by changing the speed of the turbine. Space, weight, and accessibility for repair are of greater importance in marine work; and while reliability is of course of prime importance in land practice, it is even more essential on shipboard where a failure of the apparatus may mean a great deal more than a temporary interruption of service. Ship drive however offers the advantage that motor and generator may be designed as a unit and hence obtain the best combined characteristics. Also the fact that both voltage and frequency may be varied is of help in obtaining sufficient torque during reversal. The construction of synchronous motors for ship propulsion is illustrated in Fig. 1 which shows a view of the motor installed on the S.S. *Cuba*, and in Fig. 2 which shows a section drawing of the motors being built for four new cutters for the U.S. Coast Guard Service. The stator consists of a one-piece steel frame to which the dovetail ribs and punchings are secured in the usual manner. The bottom half of the frame is cast solid but the upper half has holes for ventilating purposes. A sheet-iron duct secured to the top half of the frame leads to an external blower which draws air through the motor and discharges it either to the fire rooms or the top side. The stator coils are form-wound of rectangular wire and specially insulated against moisture and salt deposits. The coils are also capable of withstanding higher voltage than is standard for commercial machines.

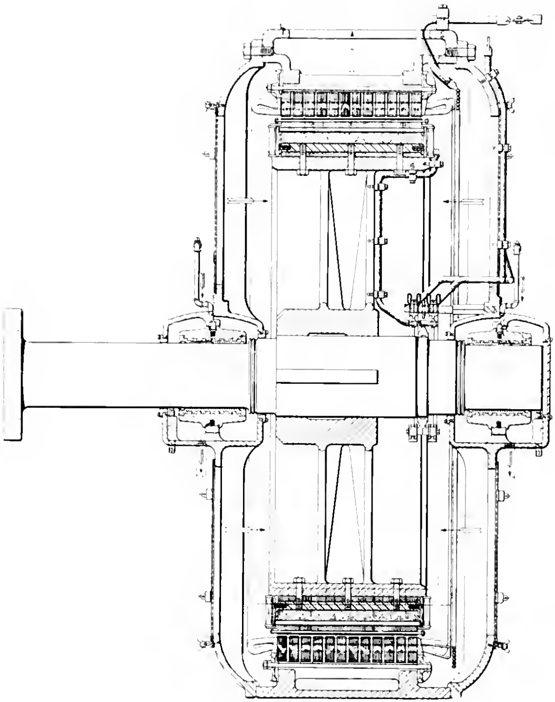


Fig. 2. Sectional View of Synchronous Motor for Four New Cutters for the Coast Guard Service

The field spider is made of cast steel and the poles are of the usual bolted type. Special provision has been made in insulating the field coils to enlarge the creepage distances and minimize danger of breakdown to ground. The amortisseur or squirrel-cage winding is considerably heavier and more rugged than is ordinarily used.

Bearing brackets are made of steel and are split along the horizontal center line to facilitate removal. The lower half of the bearing housing is made integral with the lower bearing bracket while the upper half is removable. Jacking bolts are provided for supporting the rotor when removing a bearing. The motor illustrated in Fig. 1 has the main thrust bearing* installed in the forward lower bearing bracket. This thrust bearing as well as the horizontal bearings are lubricated by an oil pump driven from the motor shaft. The pump is mounted inside of an oil tank which is bolted to the under side of the thrust bearing housing. This particular design of motor, thrust bearing, and oil system as a unit contemplated installing the motor in a separate compartment as far aft as possible and hence doing away with the usual long shaft alley. In such an installation a gravity feed oil system would be installed that could be used in case of a failure of the direct connected oil pump. With such low speeds as are employed, very little lubricating oil is required by the bearings and a comparatively small gravity tank would supply oil until repairs could be made.

Motors designed for ship propulsion must be capable of operating successfully under normal load and speed conditions, and also of quickly reversing the propeller at full speed. In normal running, the equipment must have sufficient breakout capacity so that the motor will not fall out of step due to the overloads imposed by the propeller in rough weather. From the data available it appears that the torque required at times is of the order of one and three-quarters normal. The breakout capacity is a function of the amount of field excitation on both the motor and the generator. Increasing either field or both increases the amount of load that the motor can carry and vice versa. Hence, sufficient margin in excitation must be allowed so that full speed can be maintained under all conditions of sea and weather.

Accurate data have been obtained regarding the torque required to reverse the propellers of certain classes of ships but very little is available regarding standard cargo ships. Because of the fact that the synchronous

* See article by T. W. Gordon in this issue.

motor cannot be designed to give quite as much starting and pull-in torque as an induction motor, and also because the generator, being designed for unity power-factor, is small, it is not possible to obtain sufficient reversing torque without over-exciting the generator field. It is also necessary when reversing at full speed to reduce the generator speed until the motor has been synchronized, after which motor and generator are brought up to speed together.

Where very high torque is required to brake the propeller down to zero speed against the action of the water tending to drive it as a turbine, the motor may be operated as a short-circuited generator by reversing the phase rotation between motor and generator, then establishing field on the motor but with no excitation on the generator field. It is possible to obtain more than 100 per cent torque at 70 per cent speed and over 200 per cent maximum torque with double the normal excitation on the field when the motor functions as a short-circuited generator. After the propeller is brought to rest the motor may then be started as an induction motor, brought up to speed, and synchronized. Tests made on the S.S. *Cuba*, which is the first vessel to be driven by a synchronous motor, showed that such high values of reversing torque are not necessary and that the propeller could be reversed on the induction motor torque characteristic in thirteen seconds.

Induction Motors for Ship Propulsion

By A. D. Badgley

Induction Motor Department, General Electric Company

Electric ship propulsion has been under discussion for a number of years and boats have been in successful operation propelled by direct-current motors where the power requirements have been comparatively small. For ocean-going ships where the power requirements are large it was evident that this type of drive would not successfully solve the problem. The alternating-current system was then studied with an induction motor direct connected to the propeller shaft and receiving its power from a generator driven by a high-speed steam turbine.

For ship drive the chief problem was to design the motors and generator as small, compact, and light as possible, yet in such a manner as to give the best combined operating characteristics. The principal difference between land and ship practice is that in the former the motor operates from a circuit of fixed voltage and frequency, while on shipboard the frequency is varied by changing the speed of the turbine driving the generator thus changing the motor speed. The voltage can also be varied by increasing or decreasing the excitation of the generator. This is taken advantage of to obtain the most efficient operating characteristics and at the same time to take care of unusual conditions such as occur in a storm and in maneuvering or reversing.

The air gap or clearance between stator and rotor of an induction motor is smaller than that of other types of electric motors but is of ample dimensions for safe continuous operation. With its mechanical design made very rigid to prevent distortion of the stator frame, the induction motor has earned an enviable reputation for reliability in all classes of service from the small cotton loom motor of a few watts to those of many thousand horse power responsible for carrying on the great production of our largest steel mills where reliability of operation is of supreme importance.

The reliability of an induction motor on shipboard is greatly enhanced by the ease with which temporary repairs can be made in case of an electrical breakdown at sea, without disassembling the motor, and the boat continue at full or slightly reduced speed to port.

(1) A single coil in the stator can be cut out of any circuit without affecting the speed.

(2) A single bar or turn can be cut out of the rotor without affecting the speed.

(3) A complete circuit can be cut out of either stator or rotor and the speed only slightly reduced and then only when the temperature becomes excessive, usually in hot climates.

(4) In case the stator winding is so badly burned that the foregoing repairs cannot be made, the stator leads can be disconnected, also the leads from the rotor to the rheostat; the stator terminals should then be connected together and the burned section of the winding short-circuited. The leads from the generator can then be connected to the rotor and provision can be made so that the motor can be operated inverted with both generator and motor running at about 80 per cent speed at reduced voltage.

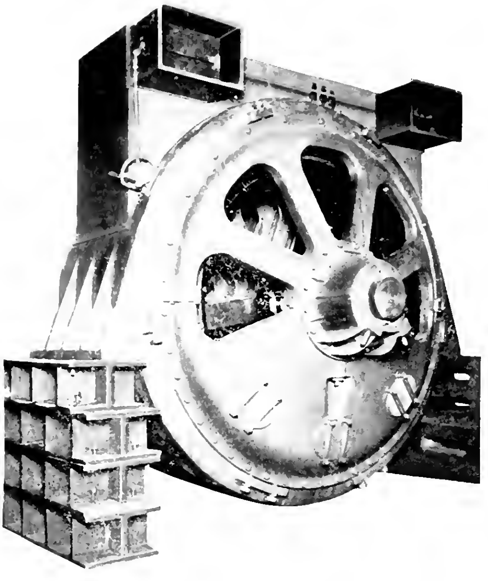


Fig. 1 A Typical Form of Induction Motor for Merchant Marine Propulsion

The motor construction is shown in Fig. 1. The essentials of construction do not materially differ from those of self-contained motors with main bearings in the end shields, as used in land practice. It is comparatively smaller in diameter and longer along the shaft, and greater care is taken to insulate the windings against moisture. A slightly larger air gap is also used.

The stator frame is made of cast iron or steel and is of a very rigid design for resisting distortion due to weight, strains, or possible magnetic pull. The bottom half is closed for water tightness, while in the top half are openings for ventilation. These are covered with a hood which connects with the ventilating system in which an exhaust fan is installed. A shutter mechanism, which is at the top and operated by a lever, can be opened when the motor is running and closed when standing still.

The stator core is built up of thin steel punchings enameled on both sides, assembled on dovetail keys fastened to ribs in the stator frame, and tightly clamped between steel flanges at each end. Air ducts are placed at frequent intervals along the core for proper ventilation.

The coils are made of several turns of rectangular wire formed accurately into shape and specially insulated to withstand the action of moisture and salt deposits. They are assembled in open slots having parallel sides and are held in place by special wedges driven in notches punched in the teeth.

The rotor punchings are mounted on a spider in a manner very similar to that employed in the stator, and the windings of insulated copper bars are assembled in slots and held in position by wooden wedges between the bars and overhung extensions of the teeth.

The winding extensions on both stator and rotor are thoroughly secured in position against movement.

The rotor winding is led to collector rings on the shaft. By means of these rings, resistance is introduced in the rotor circuit to obtain increased torque when reversing at full speed or when desired in starting or maneuvering.

The bearings are of the ball-seated type provided with oil rings and an auxiliary oil supply from the main system if required. The rings are allowed considerable movement in order to insure an ample oil supply when the boat is pitching or rolling. The bearings are mounted in housings bolted to the end shields and provided with adjusting bolts for centering the rotor in the stator. The outside ends of the housings are also provided with bolts for jacking up the shaft and lifting the weight of the rotor from the bearings so that they can be easily removed.

The shield openings are covered with removable wire screens for additional safety.

At the present time three boats are being driven by induction motors and the results of tests in each case confirm the design calculations.

The *Jupiter*, with the same type of design as that used on cargo boats, has been in continuous service since 1913.

The battleship *New Mexico*, equipped with four special two-speed induction motors for operation at either full or cruising speed at full frequency, uses two generators for full speed running and one generator for cruising speeds with all motors in operation.

The latest is the cargo boat *Eclipse*, at present on its first trip from New York to Singapore.

The reports from all three boats attest the reliability, economy, ease of control, and maneuvering qualities of the motor-driven boat both in heavy seas and in dangerous waters.

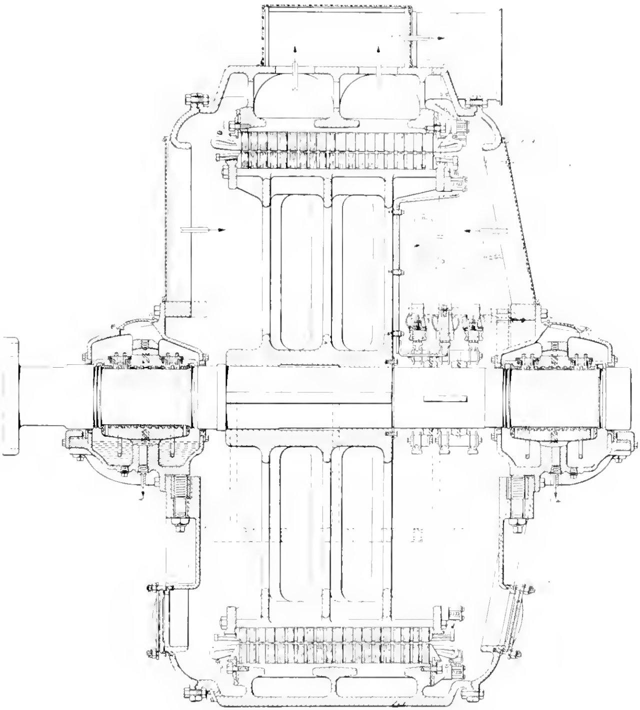


Fig. 2. Sectional View of Typical Induction Motor for Merchant Marine Propulsion

Diesel Engine Electric Propulsion for Merchant Ships

By W. H. Wild

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The Diesel engine has attained great prominence all over the world and probably no merchant ship installation is undertaken without consideration being given to this engine for either propulsion or auxiliaries or both. The increase in the number of Diesel engine installations is due chiefly to its fuel economy as compared with steam drive, and this saving in fuel is doubly desirable in ships' drive where it is necessary that valuable space be sacrificed for carrying fuel.

A large percentage of the cargo carriers now building in Europe are being equipped with Diesel engines direct connected to the propellers, and Diesel engine driven generators to furnish power for lighting, auxiliaries, and other purposes. In America there are now on order, and under construction, approximately 140,000 tons dead weight capacity in merchant motorships with every indication that this will be increased in the near future.

It is natural with so much activity in motorship construction that there be considerable discussion of the subject, and as a result technical papers have published many articles giving comparisons between Diesel engine driven ships and steam driven ships. Since relative merits of the two types of drive have been carefully covered, it is desired in this article not to compare these two types of propulsion but to invite attention to the many advantages to be gained by adopting the Diesel engine electric drive.

When selecting machinery for ships' drive the three main factors which largely determine the type adopted are:

(1) Overall economy of the equipment.
(2) Space occupied and weight of the machinery.
(3) Continuity of service.

For ships such as barges, tug boats, fishing boats, and ferries which operate in congested harbors or restricted channels, an additional factor must be considered, and that is the flexibility of control.

The majority of motorships with Diesel engines direct connected to the propellers are twin screw and the reasons for this are two-fold. First, with the present development of the Diesel engine it has seemed desirable to have two units in order to increase the reliability; and, second, twin screws permit of a higher propeller speed which is more favorable to the designed speed of many engines. In some cases, no doubt, twin screws have been adopted because the design of engine used has not been developed in sizes of sufficient capacity to furnish the total power required.

With direct-drive engines, reversal of the propeller is accomplished by reversing the direction of rotation of the engine. This requires a reliable source of high-pressure air available at all times, and also adds complications in the design of the engine. Where frequent reversals are required for maneuvering, large high-pressure air storage tanks must be provided and even with this precaution, considerable responsibility devolves upon the operator in order to avoid loss of air, which might result in serious damage to the ship in an emergency.

Often the propeller speed is a compromise between the most efficient speed of the

Fig. 1 The *Mariner:* The First Diesel Engine Electrically Propelled Vessel

propeller and the most efficient speed of the engine, which results in a loss of efficiency for both.

For ships in which it is desirable to locate the engine room amidships, there are required with the direct drive long shaft tunnels and long runs of shafting which add to the cost, friction losses and weight, and also reduce the available cargo space.

The Diesel engine electric drive when properly designed will possess nearly all the advantages accruing to the Diesel engine direct drive, will eliminate many of the difficulties encountered, and in addition will provide many advantages which are found only in the electric drive. In order to support this assumption the three main factors mentioned will be taken up separately.

First, consider the over-all economy of the equipment. The loss of energy in the electrical machines is obvious and this is usually the main objection charged against electric drive because it is so easily determined. On there is no necessity for having an engineer at the throttle or an adjustable speed governor to take care of racing,as a simple type of speed governor is all that is necessary. Another economy is effected by running the auxiliaries and lights from one of the main generating sets which should eliminate all auxiliary sets except a small one for lighting in port when all main units are shut down.

Second, consider the space occupied and the weight of the machinery. The electric drive does not require the generating sets to be placed in any definite position with respect to the propeller shaft, and therefore the main generating plant can be located to the very best advantage. Designs are being considered where it is planned to install some of the units

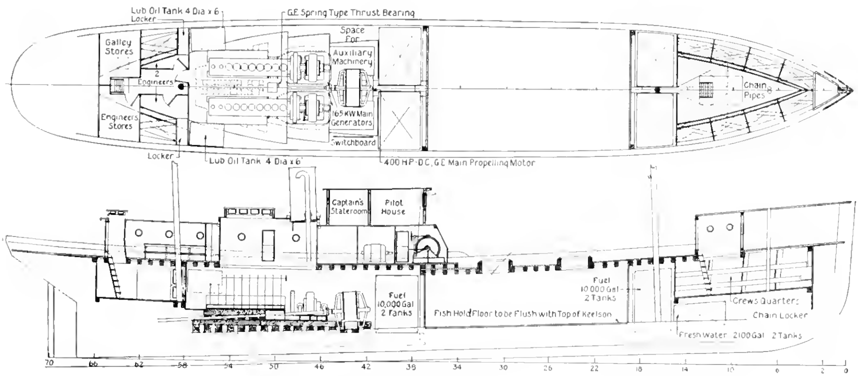

Fig. 2. Sectional Elevation and Plan of *Mariner*, Showing Location of Propulsion Equipment

the other hand, the gain in efficiency made possible by electric drive is not quite so obvious, although it will in most installations equal if not exceed the loss incurred. Electric drive permits single screw operation, even though more than one engine is used, and the most efficient propeller speeds may be adopted in either twin-screw or single-screw equipments, regardless of the number or speed of the engines used. It will permit of the constant and most efficient speed of the engines as well as the elimination of all the reversing mechanism. Also, irrespective of the ease of reversing, a propeller shaft driven by an electric motor at constant speed and torque has advantages which are not inherent with reciprocating drive. In a rough seaway, when the propeller comes out of the water, on decks one above the other, and thereby obtain a large saving in cargo space. Another saving is effected by placing the propelling motor as far aft as the structure of the ship will permit, thereby eliminating shaft tunnels and long runs of shafting.

The question of weight is largely dependent on the speed of the engine, and instead of using large, bulky, low-speed engines which involve a considerable weight, it is proposed to use smaller high-speed engines which is made possible by connecting them electrically through a motor to the propeller. The size of the unit employed will be the one most economical to manufacture, which at the same time will incorporate simplicity and reliability. In other words, the design of engine is not limited by the propeller speed and the engine

Fig. 3 Forward End of Engine Room (looking forward), Showing Main Generators and Propeller Motor with Master Controller at Right

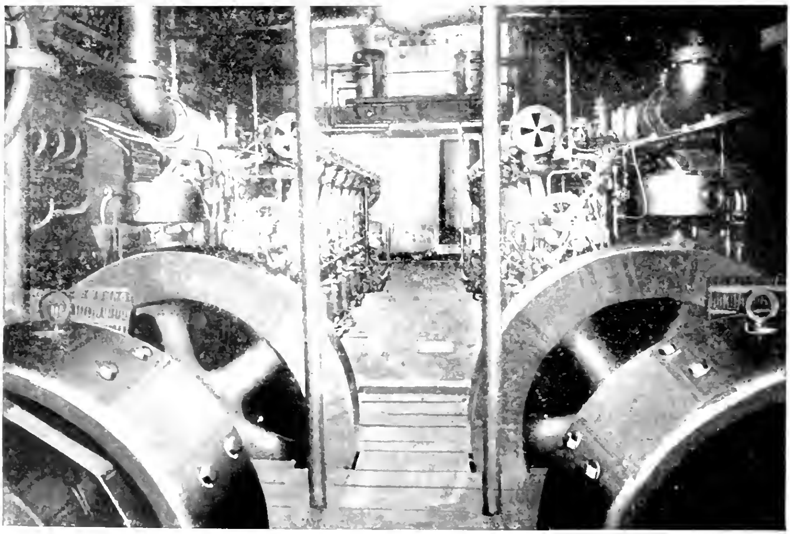

Fig. 4 Engine Room (looking aft), Showing Main Generators with the Engine Flywheels Carried on the Generator Shaft Bearings

will be run in one direction only and at constant speed. Objection may be raised to the multiplicity of parts, but this is offset by the fact that a large number of small and like parts can be manufactured with less chance of loss than a lesser number of larger parts, particularly when these are of the nature of intricate castings. From the maintenance viewpoint, the apparatus is more easily standardized and made interchangeable, so that repairs really mean replacements of parts by spares fitted to gauge.

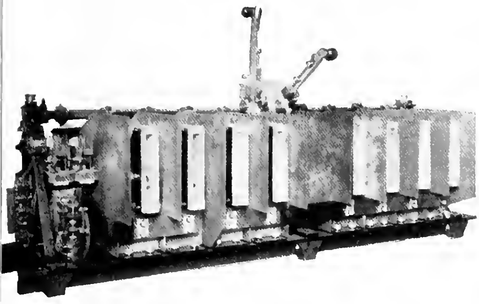

Fig. 5. Arrangement of Main Control Contactors (front view), Showing Arc Chutes and Flush Barriers

By using smaller engines, it is much easier to handle the parts when inspecting repairs. This is appreciated by engineers. Spare parts can be easily carried, and in case of break down the unit affected can be cut out of circuit, repaired, and thrown back on the line without seriously reducing the speed of the ship. This can be easily accomplished at sea by ships' engineers while with a large unit this would be very difficult if not impossible to attempt.

The electric drive immediately recommends itself for ships where great flexibility of control is an important factor, due to the fact that the most difficult operations can be reduced to the throwing of a switch or the simple movement of a master control handle. The operating controls can be placed in the pilot house as well as in the engine room with the same ease that a trolley car can be operated from either the front or rear platform.

Third, the final test for any type of ships' drive, and without which no equipment can hope to survive, is continuity of service. The equipment which can demonstrate the greatest reliability is bound to find an important place in ships where so much depends on the success of the machinery.

The major part of all movement in electrical apparatus is reduced to simple rotation which enhances the great reliability of this apparatus. Therefore, while the power is generated by engines which involve reciprocating motion, the power is transmitted to the propeller shaft through a motor which involves simple rotation only, and the generating plant can be composed of a sufficient number of units to insure one hundred per cent continuity of service without sacrificing its economy.

If there was ever any question as to the reliability of the electric driven ship it has surely been favorably answered in the success of such ships as the collier *Jupiter*, battleship *New Mexico*, and other installations equipped with electric propelling apparatus. The experience gained from the operation of the Diesel engine electric driven trawler *Mariner* has also successfully demonstrated the practical application of this type of drive. A year's operation in all kinds of weather has proved that the fundamentals involved are entirely correct, and it is of interest to note that the *Mariner* is one of a very limited number of trawlers which have been operating this past summer, the majority of the steam trawlers on the New England Coast having been tied to the docks due to the high cost of operation.

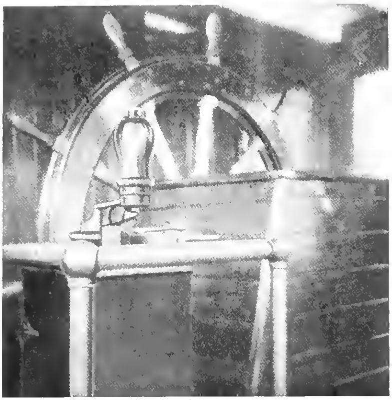

Fig. 6. Arrangement of Wheel and Master Controller in Pilot House

The Control of an Induction Motor Propelled Cargo Boat

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It is a simple matter to control a cargo boat which is equipped with a turbine-generator and propelled by a three-phase induction motor mounted on a single driving shaft. Starting, stopping, and reversing are accomplished by means of an easily operated lever which serves to close, open, or reverse the electrical connections between the turbine-generator and the driving motor on the propeller shaft. The speed of the propeller is regulated through a range from one-third to full speed by means of a second lever which changes the speed of the turbine-generator.

The efficient driving of the propeller, under varying conditions in a sea voyage, is gauged by a set of electrical instruments and governed by a third handle attached to a resistor in the generator field circuit. This handle adjusts the excitation of the generator.

The control elements of the propelling apparatus relating to these functions of starting, stopping, reversing, varying the speed, and continuously driving the propeller will be described first; then, the general control operations of the levers.

Plate I shows the relative location of the steam plant, electrical gear, and propeller shaft as installed in the boiler room, engine room, and motor room of a cargo boat.

Plate II shows details of the equipment with special reference to the flow of steam through the admission pipe and valves to the turbine and the flow of electrical power through the various conductors and switches from the generator to the motor.

The corresponding figure numbers on Plates I and II refer to the same apparatus.

Turbine Controlling Valves

Referring to Plate II, Fig. 8 is descriptive of the three main controlling steam valves which are located in the steam admission line between the boilers and the turbine.

The hydraulically operated governor-controlled steam throttle valve is used normally by the operator in controlling the turbine from one-third to full speed. Fig. 8 shows the speed lever which the operator uses normally to change his governor settings for different turbine speeds.

A second hand-operated steam throttle valve in series with the first is supplied for use, throughout the turbine range of speed, in case of failure of the governor-controlled throttle valve. It furthermore serves normally to bring the turbine up to one-third speed.

A third clapper type emergency steam valve is shown in the steam admission line for use in case of emergencies to prevent overspeeding.

Electric Gear

The generator receives its excitation from a 125-volt direct-current exciter (Fig. 5). The circuit from the exciter to the generator passes through the low-voltage field switches (called contactors) of the control group (Fig. 2). A spare exciter is installed. The excitation is adjusted by means of the resistor handle located on the control panel (Fig. 2). It will be necessary to adjust the field resistor at starting, before maneuvering, and from time to time to improve the efficiency in continuous operation at various speeds. The wheel type handle shown at the left of the panel operates the generator field resistor.

The induction motor (Fig. 4) on the propeller shaft receives its power supply from the three-phase generator through three transmission cables which pass through the high-voltage switches of the control group. The motor is started, stopped, and reversed by means of the high and low-voltage contactors of the control group. Normally in starting the motor from rest, the water-cooled resistor (Fig. 3) is inserted in the motor rotor circuit. When the motor is nearly up to speed, the water-cooled resistor is short circuited by contactors in the control group.

Referring to Plate I, Fig. 2, the two field, five reversing, and two resistor contactors are indicated in the notes.

Referring to Plate II, Figs. 6 and 7 are cross-sections of the low-voltage field contactors and the high-voltage reversing and resistor contactors, respectively. The contactors are normally magnetically operated by solenoids. The solenoids are energized by means of wires emanating from the master controller on the operating panel (Fig. 2).

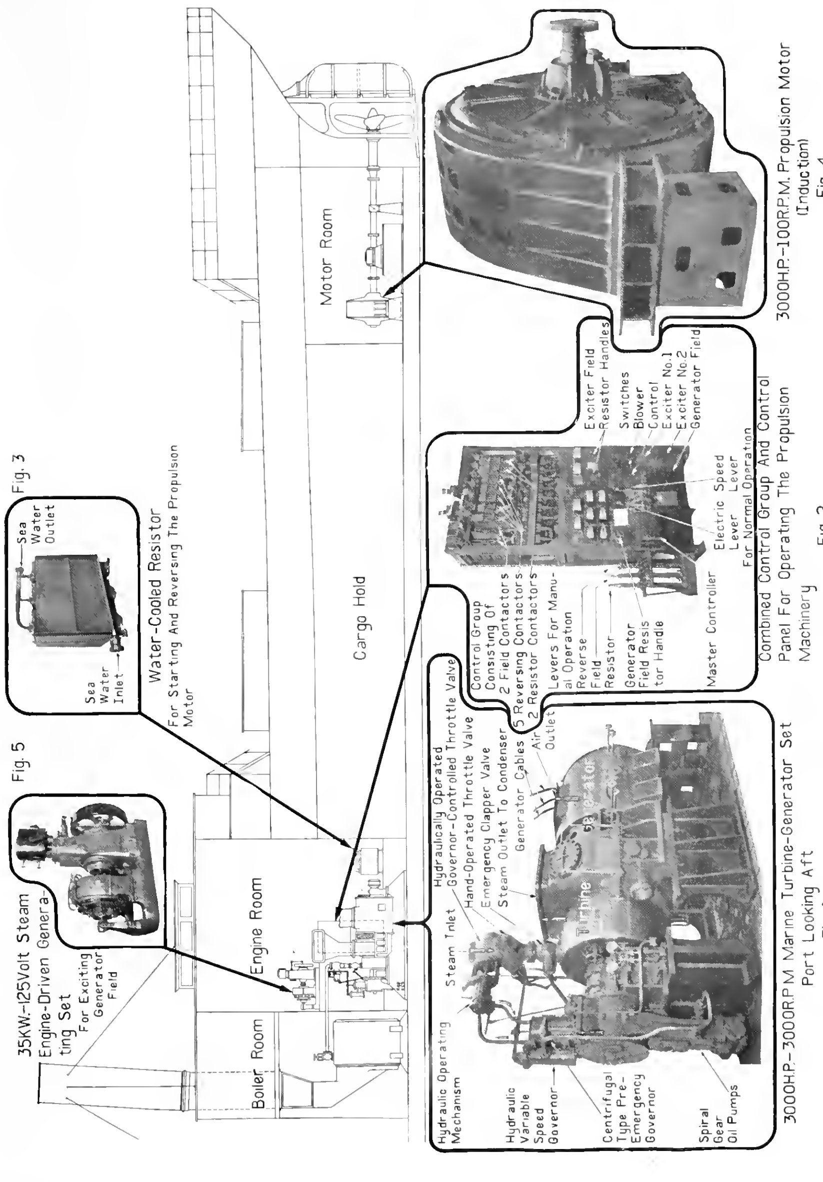

Plate I. Diagrammatic Arrangement of Electric Ship Propulsion Machinery for a Merchant Ship. Viewed from Port Side

In emergencies, they are manually operated by levers attached to three cam shafts. These levers are grouped at the left of the panel. One of these levers serves to reverse the induction motor by closing and opening five of the high-voltage contactors in proper sequence; the second operates the two low-voltage field contactors; while the third operates the remaining two high-voltage contactors for short circuiting the water-cooled resistor.

The positions of the manually operated levers are as follows:

Reverse lever	Ahead Stop Astern
Field lever	Off On
Resistor lever	Resistor Run

The contact making parts (Figs. 6 and 7) of the contactors are of the air break type equipped with powerful magnetic blowouts capable of handling the power circuit under all conditions of operation.

In reversing, the water-cooled resistor is normally inserted in the motor rotor circuit. When the motor comes up to speed, this resistor is short circuited. It is possible, however, to maneuver with the resistor short circuited. Under these conditions the motor torque at low speeds and during reversal is reduced somewhat. The motor speed is varied by varying the generator frequency. This is done by changing the turbine speed.

The control panel (Fig. 2) is a structural iron cell, faced on the front with a sheet steel plate upon which are mounted the electrical instruments and levers necessary to control the turbine, the exciters, and the electric gear. There are no exposed current carrying parts on the front of the panel.

Referring to Fig. 2, the different meters and indicators are clearly shown. Above the speed lever, which controls the speed setting of the hydraulic governor of the turbine, there are two speed indicators. One indicates the revolutions per minute of the turbine and the other the revolutions per minute of the propeller. Electric magneto-voltmeter speed indicators are used. An indicating ammeter, voltmeter, and wattmeter are placed in the main line circuits directly above the electric lever which controls the electric gear. An excitation indicator is located adjacent to the handle of the generator field resistor. The excitation indicator shows when the field resistor handle has been correctly adjusted to give efficient, stable operation at any frequency. An ammeter is connected into the field circuit of the generator. A temperature indicator reading directly in degrees Fahrenheit is also connected into the generator field circuit. There is a field resistor for each exciter field.

There are two main operating levers on the control panel. One, the speed lever, which controls the turbine governor setting, is shown with details in Fig. 8. The second lever, called the electric lever, controls the solenoid circuits of the high-voltage contactors which determine the direction of rotation of the propeller, the solenoids which close the contactors for short circuiting the water-cooled resistor in the rotor circuit, and the solenoids which operate the low-voltage contactors in the generator field circuit.

The electric lever has the following operating positions:

Ahead	Run 2 1	↑
Stop		———
Astern	1 2 Run	↓

The electric lever moves the master controller which, in turn, energizes the several contactors of the control group to give the following combinations: In the *stop* position, all contactors are open. In position *1* the main contactors, controlling the direction of rotation of the propeller, close. In position *2*, the field contactors close, putting field on the generator and giving operation ahead or astern. In the *run* position, the resistor contactors close, cutting the water-cooled resistor out of the circuit. Immediately above the electric lever is located a small red pilot lamp which is lighted when the water-cooled resistor is in circuit.

A notch is provided for the *stop* position, a single long notch for position *1* and *2*, and a notch for the *run* position. In normal operation, the operator would go directly from the *stop* position to position *2*, would delay there for a time and then would move to the *run* position. In shutting off, the operator would move through position *2* and would delay on position *1* for a moment before moving to the *stop* position. This is for the purpose of giving time for the generator field to die down before opening the main contactors.

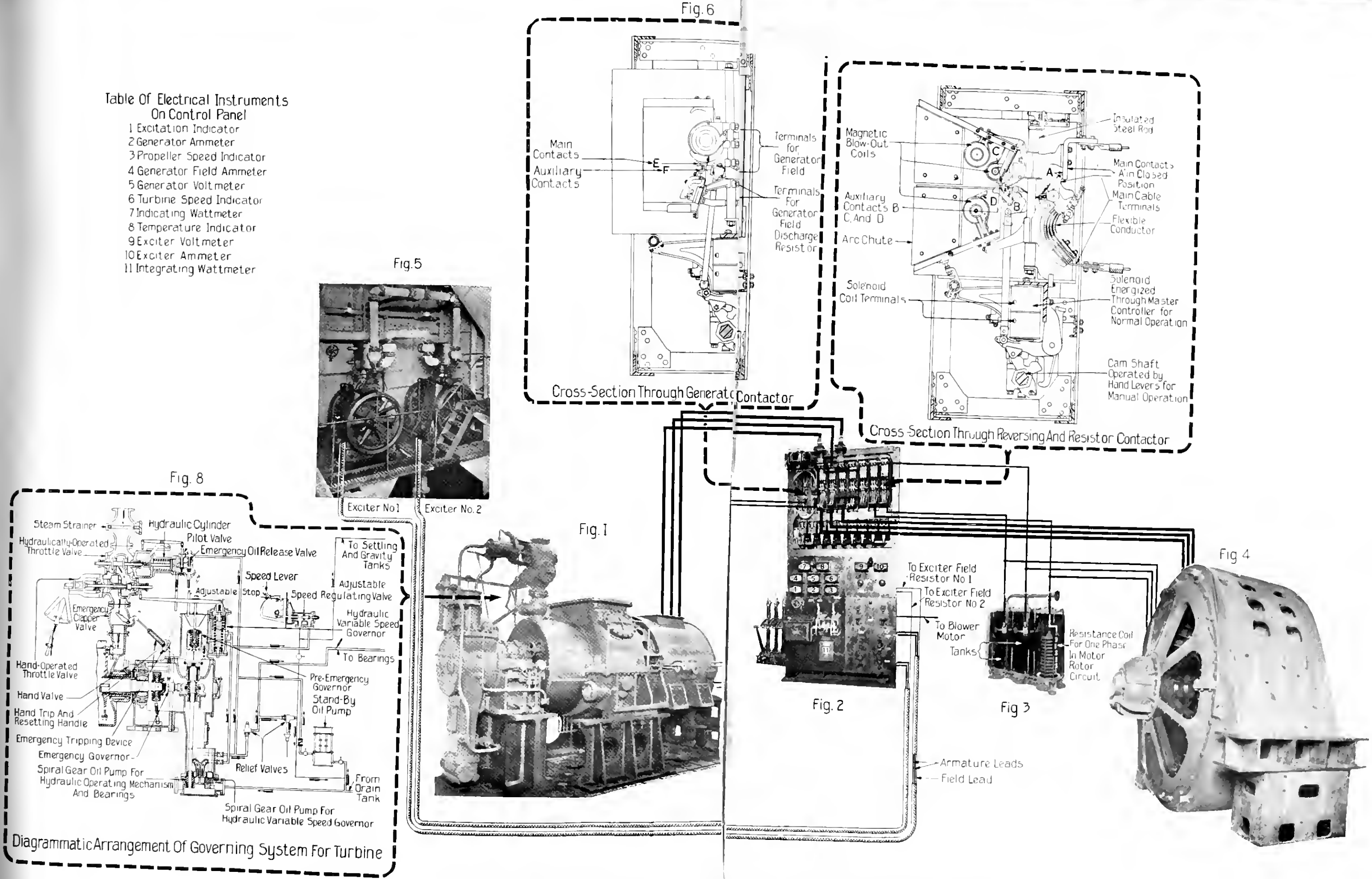

Plate II. Diagrammatic Arrangement of Steam Governing System and Electric C ns for Electric Ship Propulsion Machinery. Viewed from Port Side.

In addition to the speed and electric levers, and field resistor handle upon the control panel, there are three switch levers on the direct-current section of the panel, one for operating a combination disconnecting switch and fuse in the control circuit leading from the 125-volt power supply to the master controller for use in energizing the contactor solenoids, another lever for connecting either exciter to the exciter circuit, and a third for connecting a motor-driven blower to the power supply circuit.

The control group is located immediately above and supported by the control panel structure (Fig. 2).

Fig. 3 shows the resistor unit. It consists of three metallic resistors each made up of a series of monel metal spirals riveted together. Each metallic resistor unit is placed within a water-proof insulating shell through which is forced cooling sea water by the condenser circulating pump. Due to the fact that the metallic resistors are in direct contact with the cooling water the resistor may be operated indefinitely without overheating. The materials used in the resistors are non-corrodible. Renewable zinc plates are used to concentrate electrolysis. The resistor requires 100 gallons of circulating sea water per minute. Under normal running conditions it is short circuited but is introduced into the rotor circuit when high motor torque is desired at low speeds.

GENERAL CONTROL OPERATION

The necessary control operations in starting, stopping, reversing, varying the speed, and continuously driving the propeller will now be described. Only those turbine functions which relate immediately to the electric gear are mentioned. These control operations may be accomplished in two ways, the normal and the manual.

Normal Operation

Under normal operating conditions, the speed and electric levers on the control panel are used in conjunction with the adjacent field resistor handle and master control switch. The manipulation of these different levers is gauged by the different instrument indications.

(a) *Starting from rest.* With the engine secured, it is assumed that the emergency valve is tripped, the hand-operated throttle valve is fully closed, and the speed lever on the panel is against the *slow* stop, corresponding to approximately one-third turbine speed; also that the control and blower motor switches are open and the electric lever is in the *stop* position. When the control switch is open, the 125-volt supply to the master controller, which is turned by the electric lever, is disconnected. When the electric lever is in the *stop* position, all the solenoids of the control group are de-energized and the transmission lines between the generator and motor are open. Referring to the control group, the reverse lever for manual manipulation is in the *stop* position, the field lever for similar operation is in the *off* position, and the resistor lever in the *resistor* position.

In order to prepare for starting, the propulsion equipment is put in standby order by first setting the emergency clapper valve and emergency oil release valve, and then by slowly opening the hand-operated throttle until the governing mechanism takes control. Then the hand-operated throttle valve is opened wide. The speed lever being in the position for securing, that is, against the *slow* stop, the speed of the turbine will be limited to the slow setting.

In order to try out and warm up the turbine, the speed lever may be brought up to the *full* position while the electric gear is still de-energized. The speed lever, however, is finally placed in the *slow* position in preparation for an order to start. The turbine will then be turning at approximately one-third speed.

It is assumed that one of the exciters has been previously started and the voltage adjusted to 125 volts, that the exciter switch has been closed, and that the field switch, the blower motor, and the necessary auxiliaries are functioning. To prepare the electric gear, the control switch is closed.

When the order to start is received, the electric lever is moved through the first to the second notch (*resistor* position) *ahead* or *astern* as the case may be. When the propeller speed reaches a steady value as indicated by the propeller speed indicator, the electric lever is moved to the last notch (*run* position) cutting the water-cooled resistor out of circuit.

The field resistor handle is now turned to a position such that the needle of the excitation indicator oscillates to the left of a horizontal red line on the instrument scale. Variation to the right in the region of red shows under excitation; to the left, shows over excitation. The speed lever may now be moved, increasing the speed of the turbine as desired.

The excitation meter must be watched and the field adjusted accordingly.

(b) *Stopping.* Driving power is removed from the propeller by first turning the speed lever to the *slow* position (if not already there), then moving the electric lever to the *stop* position. In this position the power circuits between the generator and the motor are open.

(c) *Reversing with boat full speed ahead.* The levers are operated as in (b) for stopping except that the electric lever is moved through the *stop* position into notch 2 in the *astern* position. The propeller speed indicator is watched, and when the propeller speed approaches a steady value the electric lever is moved to the *run* position. After the boat has been brought up to speed, the excitation is adjusted until the needle of the excitation indicator oscillates to the left of the horizontal red line on the instrument scale.

(d) *Varying the speed.* All speed variations of the propeller are effected by changing the setting of the speed lever. The turbine can be operated below one-third speed on the governor by raising the *slow* stop and moving the speed lever below this position. The generator field resistor handle is adjusted in accordance with indications of the excitation indicator for each change of setting of the speed lever, and from time to time to improve efficiency and maintain stability of operation.

(e) *Continuous driving of propeller under varying conditions.* During a sea voyage the propeller speed indicator and the excitation indicator are the principal checks upon the operation.

Whenever a change in turbine speed and consequently boat speed is made by means of the speed lever, the field excitation should be changed by means of the resistor handle. Furthermore, changes in sea conditions, etc., which will affect the power required to drive the boat, will necessitate adjustment of the field resistor. If the excitation is low for any particular speed setting, the motor may fall out of step. If the excitation is too high, there is an unnecessary loss of energy and the economy of operation is reduced. Excitation should be maintained at as low a value as possible without the motor "pulling out of step."

The excitation indicator is a measure of the correct excitation under all conditions of sea and speed. The scale of the indicator is calibrated from right to left with divisions running from 0 to 10. The correct excitation is maintained in the generator field by adjusting the field resistor handle so that the pointer of the excitation indicator will closely approach but not swing to the right of zero. The scale of the excitation indicator is marked with a red band extending from zero to the right. If the pointer is on this red band, the motor, when in operation, is either in danger of "pulling out of step," or has actually "pulled out of step."

(f) *Protective devices.* In addition to the automatic oil governor, the turbine is protected against over-speeding by a pre-emergency centrifugal governor and by an eccentric ring emergency governor (Fig. 8).

Protective fuses are located in the low-voltage control circuits.

Overheating of the generator field is shown by means of the temperature indicator in the field circuit. This indicator has broad red markings on the scale in the region above 300 deg. F. and when the needle registers in this region the generator field is overheated. Overheating of the generator field under bad sea conditions is an indication that the boat is being maintained at too high a speed and that the turbine speed lever and then the field resistor handle should be reduced in setting. Decreasing the turbine speed will permit, as shown by the excitation indicator, lower excitation on the generator because of the lower power demand, and the heating will be reduced correspondingly.

Taking the temperature indicator in combination with the excitation indicator, the former serves to show the maximum possible field without overheating, and the latter the minimum generator field necessary to hold the motor in step.

Manual Operation

If for any reason it is necessary or desirable to operate the control group directly, that is, manually, this may be accomplished by means of the reverse, field, and resistor levers already described which, through the means of cam shafts, actuate the contactors directly. The solenoids are not necessary for operation in this case.

The control group can be operated in conjunction with either the speed lever on the panel or with the hand-operated throttle valve directly on the turbine (Fig. 8). When the hand-operated throttle is used, during maneuvering, the turbine is held at approximately one-third speed or less while the contactors of the control group are being manipulated.

The turbine speed is shown by the indicator on the control panel.

(a) *Starting from rest.* With the turbine running at one-third speed, the reverse lever at the left of the panel (Fig. 2) is moved manually to either the *ahead* or the *astern* position. Then the field lever is moved to the *on* position. When the propeller speed indicator reaches a steady value, the resistor lever is moved to the *run* position and the speed of the turbine is increased as desired. The excitation meter is watched and the field adjusted accordingly.

(b) *Stopping.* The speed lever is moved to the one-third speed position, the resistor lever is moved to the *resistor* position, the field lever is thrown to the *off* position, and then the reverse lever is moved to the *stop* position.

(c) *Reversing with boat running full speed ahead.* First the speed lever is moved to the *slow* position. Next the resistor lever is moved to the *resistor* position and the field lever to the *off* position. Then the reverse lever is moved from the *ahead* to the *astern* position, and the field lever to the *on* position. Finally, when the propeller speed indicator has reached a steady value, the resistor lever is moved to the *run* position.

In case the hand-operated throttle valve is used in (a), (b), or (c), in place of the speed lever, the turbine speed indicator must be used to gauge the throttle opening, thus controlling the turbine speed.

(d) *Varying the speed.* Speed variations are effected either by the speed lever or by the hand-operated throttle valve.

(e) *Continuous operation.* Stable efficient operation is maintained by adjusting the generator field resistor on the control panel in accordance with the excitation indicator.

CONCLUSION

It may be of interest to compare reversal operations of boats propelled by direct-connected reciprocating engines, by geared turbines and by electric drive.

A reversal with the reciprocating engine is accomplished by closing the throttle, reversing the engine valve gear and again opening the throttle.

A reversal with a geared-turbine boat is brought about by closing the *ahead* throttle and opening the *astern* throttle, thus changing the flow of steam from the main ahead turbine to the astern turbine.

A reversal with electric drive is accomplished by merely reducing the turbine speed with the speed lever and then throwing the electric lever from *ahead* to *astern*. If the turbine is already running at reduced speed, as would be the case in maneuvering, it is only necessary to throw the electric lever.

Referring to Table I, a reversal with either a direct-connected reciprocating engine or geared turbine necessitates bringing the engine to rest and then up to speed in the opposite direction. With the electric drive, the turbine always revolves in the same direction. It is accordingly much simpler and easier to maneuver a boat equipped with electric drive.

TABLE I

COMPARISON OF OPERATIONS IN REVERSING A SINGLE SCREW BOAT PROPELLED BY A RECIPROCATING ENGINE, A GEARED TURBINE, OR ELECTRIC DRIVE

Operation	Reciprocating Engine	Geared Turbine	Electric Drive	
	Slow and Full Speed Reversal of Ship	Slow and Full Speed Reversal of Ship	Slow Speed Reversal of Ship	Full Speed Reversal of Ship
1	Stop Driving Power of Engine by Closing Throttle Valve	Stop Driving Power of Turbine by Closing Ahead Throttle Valve		Reduce Turbine Speed with Speed Lever
2	Reverse Valve Gear		Reverse Electric Gear with Electric Lever	Reverse Electric Gear with Electric lever
3	Start Driving Power of Engine by Opening Throttle Valve	Start Driving Power of Turbine by Opening Astern Throttle Valve		Increase Turbine Speed with Speed Lever

Control Equipment for Auxiliaries in the Merchant Marine

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Electric appliances for the control of motors operating auxiliary machinery installed on merchant vessels primarily conform to the accepted standards of engineering practice as established by the published rules or codes of the American Institute of Electrical Engineers, the National Board of Fire Underwriters, and the Electric Power Club. The adaptation of any equipment to withstand the severe atmospheric conditions and sea-water immersions imposed upon it requires special consideration and development of ways and means of rendering it immune to the corrosive action of salt-laden air, mist, and water.

It is quite obvious that satisfactory operation in this service cannot be expected of devices designed with no contemplation of their use for other than industrial applications on land, where such devices do not ordinarily include non-corrodible small parts in their mechanisms, or non-absorbent insulations in their structures, not to mention such other considerations that affect their proper and reliable functioning when subjected to the pitch and roll of a vessel and the vibrations peculiar and inherent to shipboard installations.

Appliances constructed to make use of the force of gravity for the operation of any of their functions should therefore not become unreliable when inclined to an angle (30 deg. adopted by the Navy Department) in any direction. The requirement of satisfactory operation when inclined should not be confined by specification to gravity operated devices, these being cited only as an example; it is generally understood to include all automatic and magnetic devices, such as contactors, relays, and circuit breakers.

The location of the appliance, the method of operation, and the protection it should be afforded against mechanical injury, salt-water immersion, and unauthorized manipulation, as well as the provision of proper ventilation during service, are important factors governing the design and form of its housing.

The following paragraphs are descriptive of control apparatus suitable for marine service:

When the motor to be controlled does not exceed the reasonable limit to which manually operated controllers are applicable, it seems to be generally more satisfactory to employ the hand-starter type of panel and the drum controller as these are more readily understood and repaired by the ship's operating force than are magnetic equipment.

Fig. 1 shows a compact hand starter, suitable for the control and protection of small motors such as are used for hull ventilation fans and machine tools. Adjustable speed is obtained by means of field control. The omission of the field rheostat makes this panel also suitable for motors without speed adjustment, such as fresh water or other small pumps.

Overload protection is provided by means of enclosed fuses, and two spare fuses are included and mounted in clips on the panel to be readily available in case of emergency.

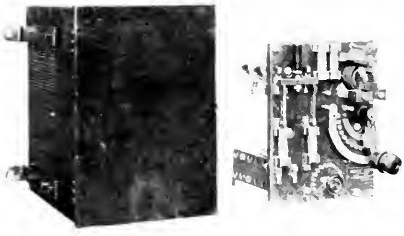

Fig. 1 Non-watertight Manual Controller, for Hull Ventilation, Pumps, Machine Tool and Miscellaneous Small Motors Requiring 30 Amps. or Less

Low-voltage protection is provided in the combination of contactor, starting dial switch, and scheme of wiring, whereby it is made necessary after a shutdown for the operator to return the dial arm to the starting position to reset the contactor and again start the motor, in the usual manner, by the manipulation of the dial switch arm which short circuits the starting resistance step by step.

It is not intended that the speed of the motor be regulated by armature control and therefore the starting resistor is not of sufficient thermal capacity to stand continuous operation without attaining excessive temperature; so to guard against the possibility of running the motor on any starting button, the dial arm handle is arranged with a push contact connected to the operating coil circuit of the contactor, making it necessary for the operator to maintain this circuit during starting. If the operator removes his hand, or relieves the pressure upon the push handle contact before reaching the full running position, the contactor will be de-energized and open its contacts. The starting operation will then have to be repeated, with the dial arm brought back to the first starting button. The panel being intended for interior installation is mounted in a ventilated enclosing case with hinged door which may be locked to prevent tampering.

Fig. 2 is a drum controller of the non-watertight type and to all appearances is a standard commercial product, but a close examination will reveal the modifications which have been incorporated to make it suitable for the exacting conditions that have been pointed out. These modifications usually

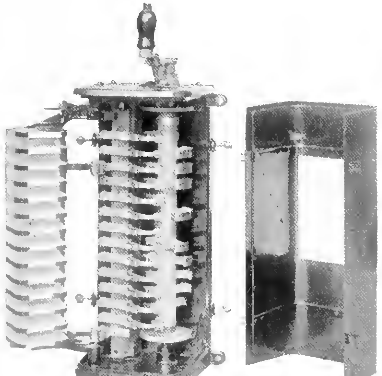

Fig. 2. Non-watertight Drum Controller, for Deck Machinery, Engine-room Auxiliaries and Miscellaneous Motors Requiring Over 30 Amp., Where Installation Conditions Permit a Non-watertight Controller

include brass bushings for the operating shafts, and making non-corrodible all small steel parts, such as pins, screws, washers, and springs.

Such controllers are sometimes installed below deck in a protected location and are operated from a weather deck station by mechanical means. Handles, working in a vertical plane, commonly called "pump handles," the movement of which corresponds to the desired direction of movement of the load, are a convenient means of operating controllers for hoists and cargo winches.

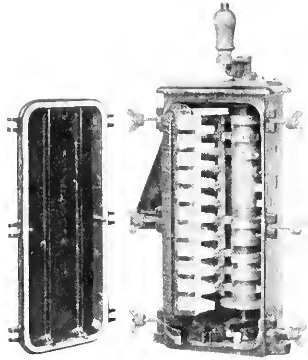

Fig. 3. Watertight Drum Controller, for Same Purposes as Non-watertight Controller, but Where Installation Requires Watertight Feature

It is sometimes desirable to locate the drum controller on the deck and the resistor below deck in a protected place or in a separate enclosure above deck, as in the base casting of a winch, in which case watertight drum controllers are provided. The electrical equipment of cargo winches, windlasses, and capstans installed on the weather deck of a vessel must be proof against leakage when immersed and sufficiently rugged to withstand the wash and pounding of the sea during a voyage.

Fig. 3 shows a watertight drum controller capable of submersion without leakage. The non-corrodible features of the internal parts as well as the clamping devices are adhered to in this type of controller to the same extent as in the open type.

On cargo vessels it is often difficult or at least impracticable to assign a sufficiently protected location in which to install the control equipment of the deck machinery. This fact has resulted in the evolution of some very unique designs of units comprising drum controller, protective panel, and resistor in watertight housings, for installation on the weather decks to control the cargo winches, windlasses, and capstans.

Cargo winches are used ordinarily when the vessel is at a dock or in any event when cargo hatches are open and therefore at times and under conditions not exposing the control equipment to the direct splash of sea water. Under this condition watertight

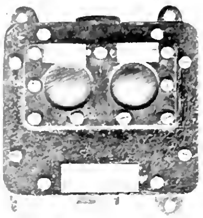

Fig. 4. Watertight Push-button Station

covered ventilators or operating doors, giving the equivalent air circulating facilities for removing the heat dissipated by the resistor, are arranged to be readily opened.

When the capacity of the equipment exceeds the practical limit for drum controllers, watertight master controllers and push buttons are located on deck and their magnetic

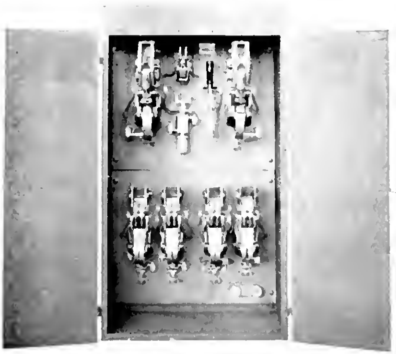

Fig. 5. Non-watertight Magnetic Controller, for Engine-room Auxiliaries, and Typical of Construction of Panels for Magnetic Control of Deck Machinery

control panels in some compartment below. Fig. 4 is a watertight push-button station suitable for marine service and capable of adaptation to the requirements of the system of control with which it may be used. That is, it may take the form of one, two, or three buttons arranged to perform such functions as "Start," "Stop," "Forward," "Reverse," "Hoist," or "Lower," or any combination of these, where a momentary contact making or breaking master switch is applicable. The interior fittings are arranged to multiply the comparatively small movement of the operating button into a sufficiently large movement of the contact tips.

Fig. 5 is a typical automatic panel with non-watertight enclosing case, suitable for automatic acceleration of large pumps, which may be arranged to start by a local switch or push button or remotely by either of these appliances. The selection of a starting switch

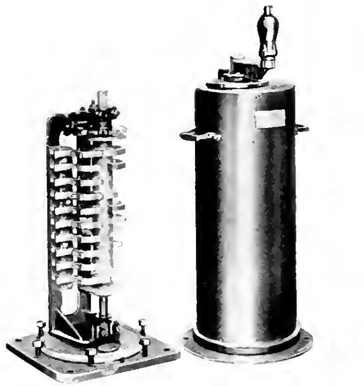

Fig. 6 Watertight Master Switch, for Weather Deck Mounting to Control Magnetic Controllers of Deck Machinery

or push button depends on whether the equipment is required to have under-voltage release or under-voltage protection. In the case of the main circulating pump it is generally desired to have under-voltage release, which means that the pump will automatically restart without delay upon the re-establishment of approximately normal voltage. This method requires a switch.

Fig. 6 illustrates a watertight master switch for the remote control of a magnetic panel having the general characteristics of that shown in Fig. 5. This master switch is not only watertight but practically non-fragile, its base and frame being constructed of malleable iron and having a cover made from a piece of steel tubing with welded-in top plate.

The external connecting leads are carried into the controller in the form of a multi-conductor cable, passing through a stuffing tube, located in the base plate, for which a drilling boss is provided. The rubber gasket is in the form of a large washer, the joint made by the edge of the cover in contact with it resembling the efficient method employed in sealing airtight glass preserving jars.

The handle is arranged to connect with the cylinder shaft through a packed gland device permanently carried on the cover head, but the handle may be readily removed and used to operate the cylinder when the cover is off, if it is desired to inspect and check the adjustment of the fingers in contact with the drum.

Several methods of electrically controlling the movements of the rudder by power from remote stations on the bridge or in the pilot house have been developed, and all of these systems necessarily involve the use of the most reliable and ruggedly constructed magnetic panels and master switches procurable.

Fig. 7 illustrates a type of panel suitable for the control of a small motor which may be connected directly to the rudder mechanism of a small vessel, but more often to the pilot motor connected to the valve gear of a steam steering equipment in which case the motor acts in the capacity of an electric telemotor. The panel referred to is arranged to run the motor in either direction and to stop the motor promptly by dynamic braking.

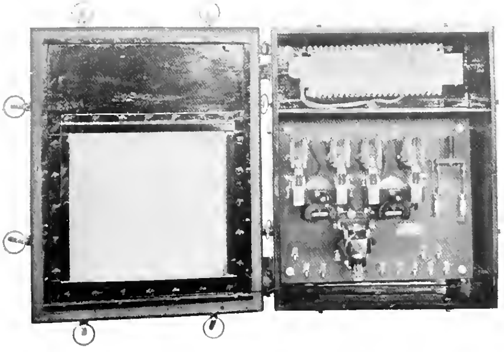

Fig. 7. Non-watertight, Dust-proof Enclosed Magnetic Controller, for Small Steering Gear or Pilot Motor on Large Steering Gear

The double-pole reversing contactors are mechanically interlocked to prevent short circuit on the line, and the dynamic-braking contactor is mechanically interlocked to both reversing contactors so that interference of the braking effect cannot exist while power is being applied in either direction of operation. The dynamic-braking contactor is energized by the counter-electromotive force of the motor armature which renders this reversing and dynamic-braking unit proof against the occurrence of that severe condition of rapid reversal known as "plugging."

Fig. 8. Watertight Master Switch, for Control of Frequently Reversed Magnetic Controllers, Such as Steering Gear

Fig. 7 also illustrates a type of resistor unit having desirable characteristics to recommend its use in marine installations, being constructed of non-corrodible alloy high-resistance wire or ribbon, wound upon porcelain or non-fragile compound insulators as desired, the insulators being in turn supported by a punching of steel plate. The steel plate is protected from corrosion by sherardizing.

This panel may be satisfactorily operated by a small but rugged master switch as shown in Fig. 8. Larger master switches of the pedestal type for mounting upon the deck may for various reasons be preferred, but from a purely electrical standpoint the small master switch is duly qualified.

This small switch is watertight, being designed with an adjustable stuffing gland around the operating shaft and a screw-on cover with a rubber-washer gasket. The entire switch is composed of very few parts all of which are easily accessible for removal or renewal by taking off the cover. The frame and cover being of brass eliminates the liability of the screw threads of the cover corroding and "freezing" the cover on.

Watertight limit switches for stopping the motor when the rudder has reached either

Fig. 9. Direct-current Contactor with Series Current-limit Interlock

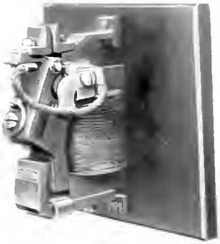

Fig. 10. Spring Adjustable Current-limit Contactor

extreme angle of movement are provided with steering gear equipments when the system of control is such as to require them. These limit switches are quite similar in construction to the master switches, but have an operating arm carrying a roller at the engaging end.

Cast-grid units mounted upon insulated tie rods form the most practical and durable resistors for heavy starting and speed regulating duty. Such resistors may be assembled in pressed-steel end frames having feet or lugs, thus forming sections adapted for mounting on bulkheads, on the under side of decks or for stacking one above the other. A very convenient method of stacking is to provide a structural angle frame upon which the sections may rest and be secured but permitting of the removal of any section without disturbing the others.

For smaller ampere capacities and higher ohmic values, the units described in connection with Fig. 7 have given very satisfactory service.

Fig. 9 shows, in greater detail than can be seen in Fig. 5, a typical direct-current contactor with series current-limit interlock attached. The current-limit interlock is mechanically restrained from prematurely closing its contacts by its interlocking with the moving element of the contactor, thus the sequence of closing of the contactor which the relay governs is assured as well as at the proper current values. Mechanical and electrical interlocks are readily attached to this type of contactor to facilitate the working out of protective and co-operative schemes with its application.

The contactor shown in Fig. 10 is typical of a line of spring adjusted series current-limit contactors. A contactor of this type automatically short-circuits a step of the starting resistor as the motor accelerates. It is operated directly by the motor current in such a way that it remains open on high values of current and closes at a predetermined adjusted value which occurs upon sufficient acceleration of the motor.

A noteworthy example of an application of this type of contactor is in the series current-limit starting panel shown in Fig. 11. This panel is designed for the purpose of keeping the accelerating peaks of fan, blower, and pump motors within the limits for which the fuses are suitable to protect the motor under normal conditions, when these auxiliaries are remote from the distribution switchboard at which they are started and stopped by simply closing or opening a fused line switch.

The panel is novel in its design in the following particulars:

(a) The electrical parts are assembled and wired as a unit which may be removed from the case by the removal of two bolts.

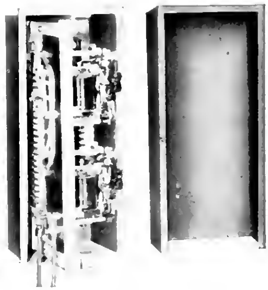

Fig. 11. Series Current-limit Starting Panel

Fig. 12. Universal Overload Relay

(b) The electrical unit is so supported in the case that all connections, front and back, are readily visible and accessible.

(c) The contactors are entirely outside the case, when the cover is removed, thereby affording exceptional facilities for making adjustments.

(d) The terminal studs are arranged to support the leads and no drilling or bushing is required in making the installation.

(e) The enclosing case is proof against the entrance of water which may drip upon it.

(f) The enclosing case and cover are each developed from one piece of heavy sheet steel with welded joints.

The case and cover are sherardized after welding. The flange of the cover is made to engage the flange of the box tightly when in place by the flat roll springs shown attached to the angle-iron supports.

The case is furnished without feet or lugs and is undrilled for supporting screws or rivets. In making the installation on board a vessel, the electrical unit is removed and retained in safe-keeping by the electrician and the enclosing case delivered to the ship fitters for securing in place. The box may be bolted or riveted to the ship's structure with an insertion of canvas soaked in red lead, and afterwards painted as a part of the structure. This method of attaching the panel case eliminates possibilities of areas on both the case and bulkhead which are inaccessible for the application of the usual periodical coats of paint for the preservation of the steel.

After all structural and painting work is complete it is a simple matter to place the electrical unit in the box, connect the external leads to the terminal studs and attach the sliding cover.

A universal relay for overload protection is shown in Fig. 12. This relay is available in forms to provide: instantaneous or inverse time-element release; resetting by gravity, electricity, or hand; may be used with direct or alternating current; and may be fitted with ordinary service or extreme shock proof latch. Both time and current functions are adjustable.

The foregoing is a résumé of s me of the types of electric appliances which have been evolved to fill a comparatively recently created field of application.

The superiority of electric drive for ships' auxiliaries, while being recognized in the past, has not been taken advantage of to as great an extent as its merits invite, probably accounted for in a large degree to the undeveloped state of suitable equipment.

With the impetus now gathered in this direction we may reasonably expect that the merchant marine electrification of auxiliaries will in the future keep pace with other industrial electrifications.

Spring Thrust Bearings for Propeller Shafts

By T. W. Gordon

Alternating-current Engineering Department, General Electric Company

The General Electric Review for February, 1919, contained an article on "Single-Collar vs. Multi-Collar Thrust Bearings for Propeller Shafts," in which Mr. H. G. Reist pointed out the advantages of a single-collar thrust bearing. It was shown that the friction loss in a single-collar thrust bearing is much less than that of the multi-collar horse-

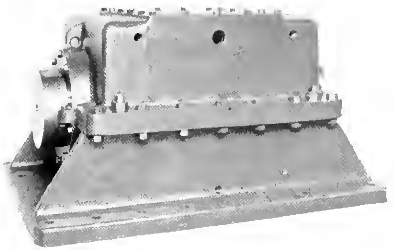

Fig. 1. Spring Thrust Bearing and Housing with Dummy Shaft for Marine Propeller Shaft

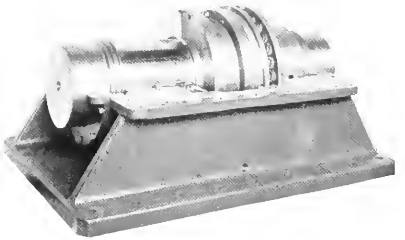

Fig. 2. Spring Thrust Bearing Showing Method of Attaching Rotating Ring of Bearing to the Shaft

shoe thrust bearing which has been in general use for many years. The use of single-collar thrust bearings has proved that it is safer to carry the load on a single bearing with high unit pressure than to try to obtain a low unit pressure by more or less unsuccessful distribution over six or more bearings. The dimensions, weight, and first cost of a single-collar bearing are less than for a multi-collar bearing.

The spring-supported thrust bearing to be described is a single-collar bearing. Two designs will be shown, one in which the thrust bearing parts are in a housing for installation between the engine or driving motor, and the propeller; and another design in which the thrust bearing parts are located at the forward end of the shaft in a housing integral with the motor shield or reduction gear casing.

Fig. 3 shows a cross-section view, and Figs. 1 and 2 are photographs of a spring-thrust bearing and its housing which will be installed on the electrically propelled U.S. Coast Guard Cutters. The propeller shaft has a solid flange which is recessed on both sides to receive the rotating rings of the ahead and astern thrust bearings. This construction has advantages over a double-faced runner, made in halves and clamped around the shaft. For large propeller shafts the two-faced runner is heavy, and in storage or in assem[illegible] the shaft there is a great danger of [illegible] two polished rubbing surfaces. [illegible] the propeller shaft pro[illegible] for two light runners, or rotating rings. These rings (Fig. 4) are made in halves and, in addition to being of light weight, they have only one side polished. The rings are therefore easily assembled on the shaft or stored as spare parts. The rotating rings are held in the recesses in the shaft flange by small bolts.

The thrust from the propeller shaft is received by the stationary babbitted rings and transmitted through springs to the thrust bearing housing. An initial compression, which corresponds to about double the normal propeller thrust, is put on the springs by a screw and washer. Any very high local pressures that may occur on the bearing due to inaccuracies in workmanship or alignment will be relieved by a further compression of the springs at the points where the abnormal pressures occur. The initially compressed springs act like a series of safety valves behind the babbitted plate and provide a support which will yield at any point before the pressure reaches a value that will cause dragging of the babbitt. The thrust bearing as a whole will remain solid and will not move until very much overloaded. In case of a very heavy momentary thrust or blow on the propeller, all the springs will yield slightly and the blow be absorbed in a movement of the shaft. The relieving of heavy shocks by the cushioning effect of the springs will greatly diminish the chances of wiping the babbitted surface.

The maximum movement of the springs is limited to $\frac{3}{32}$ inch before the babbitted

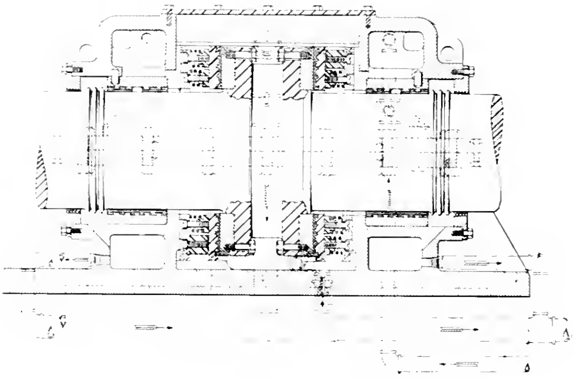

Fig. 3. Longitudinal Section of Spring Thrust Bearing and Housing for Marine Propeller Shaft

plate will come against stops. These positive stops guard against any objectionable axial movement of the propeller shaft, which might occur in a bad storm, and also prevent the springs from closing too tightly. If the flexible babbitted stationary ring is ever pushed back $\frac{3}{32}$ inch against the stops, the babbitt in line with the stops will not be damaged because the pressure on the stops will only be the difference between the thrust and the total supporting power of all the springs.

Two journal bearings are provided in the thrust bearing housing to carry the weight of the section of the propeller shaft near the thrust bearing. Oil deflectors turned on the shaft, just outside the journal bearings, throw from the shaft the oil which passes through these bearings. The oil is collected in a chamber below and conveyed to a sump tank, together with the oil discharged through the overflow pipe from the thrust bearings in the center of the housing.

Fig. 1 shows a photograph of one of the bearings, with a dummy shaft, for the U.S. Coast Guard Cutters. The same bearing is also shown in Fig. 2 with the top half of the housing removed. One half of the rotating ring of the thrust bearing at the left has been removed and also the top half of the babbitted plate, springs, and journal bearing. It is not necessary to remove the upper half of the housing to install a new set of babbitted rings and rotating rings. This work can be done with the upper part of the housing in place by removing the light cover which is bolted to the top of the housing.

Fig. 2 shows the spring-thrust bearing located at the forward end of the shaft of the propulsion motor on the S.S. *Cuba*. A full view of the forward end of the complete motor will be found elsewhere in this issue in an article by E. S. Henningsen. This bearing is contained in the end bracket of the motor, which is specially designed to transmit the thrust to the motor frame and foundations. When the thrust bearing is at the end of the shaft, it is possible to use a bearing smaller in diameter by reducing the size of the shaft. The runner in this bearing is a solid ring, polished on both sides. It is assembled on the end of the shaft and held in place by a plate and several bolts, or by one large nut. The flexible babbitted rings are similar to those

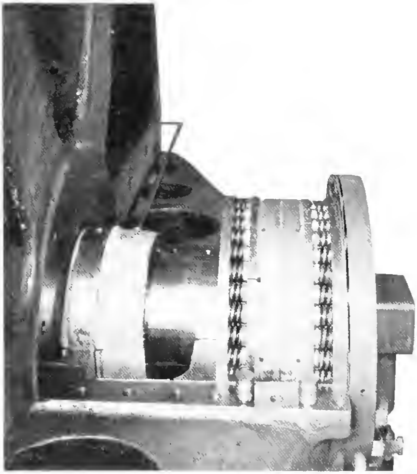

Fig. 5. Spring Thrust Bearing for Propeller Shaft of S.S. *Cuba*
The thrust bearing is at the forward end of the shaft in the bracket of the driving motor

for the bearing in Fig. 3 except that it is not necessary to make them in halves. These spring thrust bearings are immersed in a bath of oil. For the larger sizes, oil is supplied continuously from an external system. The incoming oil keeps the housing full at all times and carries off the frictional heat from the bearing. The type of bearing shown in Fig. 4 may also be used to advantage in a housing integral with, or bolted to, a reduction gear casing.

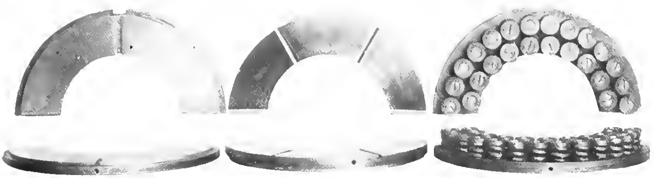

Fig. 4. Stationary Babbitted Ring, Rotating Ring and Springs of a Spring Thrust Bearing for Marine Propeller Shafts

Switchboards for Merchant Ships

By P. J. Whitmore

Switchboard Department, General Electric Company

A consideration of switchboards for use on merchant ships brings to attention two types differing in appearance and function. One controls the electric propulsion machinery, and the other the general distribution circuits, and each type may be viewed merely as another of the many varied forms of panels which have been developed to meet particular and exacting requirements.

Switchboards for the Control of Electric Propulsion Machinery

The distinction is rather well defined between the switchboards used to control electric propulsion machinery and those used to control the general distribution circuits. This is due to the use of alternating current for the propulsion machinery, to the relatively large capacity and the comparatively high voltage of the apparatus controlled, and to the added requirements of controlling turbines, generators, and motors for maneuvering the ship.

A typical switchboard for the control of propulsion equipment on a merchant ship is shown in Fig. 1. The turbine and electrical machinery are controlled entirely from this board. By an arrangement of contactors mounted above the switchboard proper, the electrical connections are made and broken between the turbine generators and the propulsion motors. The panel in the lower right-hand side is for the control of auxiliary circuits used in connection with the propelling equipment. These switches are of the dead-front type and are further illustrated in Fig. 2. A detailed description of the propulsion control functions of such switchboards is given in R. Stearns' article in this issue.

Switchboards for the Control of General Distribution Circuits

On ships equipped with electric auxiliaries, the generators for supplying the power may be of considerable capacity, and therefore a large number of feeder circuits may be required.

Fig. 2 shows a dead-front board for the control of two auxiliary generators and a balancer set, as well as the control for the distribution of power and lighting throughout the ship. Some interesting features of switchboards for this service are as follows:

Each lever switch is of the dead-front variety and is a unit in itself. It is mounted in the switchboard by four bolts, one in each corner of the supporting steel plate. The switch can be locked in the open position by a padlock, the loop of which is passed through a hole in the operating handle. A steel cover allows access to the fuses from the front of the panels, but only when the switch is open. The

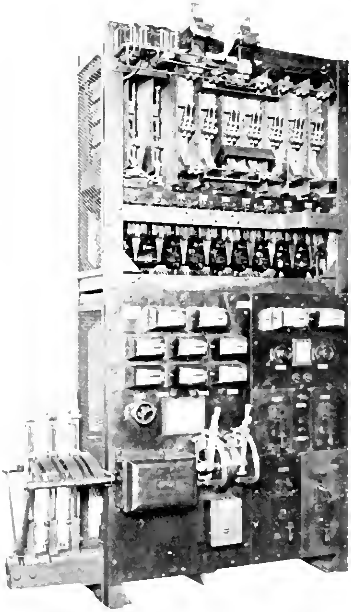

Fig. 1. Typical Switchboard for the Control of the Apparatus and Circuits on an Electrically Propelled Vessel

mechanical construction prevents closing the switch while the fuse cover is open. Whenever the switch is open the fuses are dead and can be examined or replaced without danger.

With feeder switches of the dead-front type the connections between switches and bus bars can be made advantageously and present a convenient and compact arrangement. The ends of the switchboard are enclosed with grille work and means for entering is provided by placing doors at both ends.

The dead-front circuit breaker used on this board is in general construction the same as the standard type of air circuit breaker, the difference being that the operating handle is modified and the magnetic blow-out coil is omitted. The breakers are mounted back of the board and provision is made for tripping them manually by means of a button from the front of the switchboard. They are accessible when the steel panel in front of the breaker unit is removed. Each breaker is closed in the same manner as the usual type of manually operated overload air circuit breaker.

As electricity comes into general use on vessels more attention will be paid to the safety features and eventually boards of this dead-front type, affording protection at all times to the operator, will become standard for this class of installation.

Requirements for Sea Service

The assembly and arrangement of apparatus and equipment has been touched upon, but the differences in equipment for sea service and land service have not been shown.

The essential qualifications for sea service are:

(1) Instruments should be moisture proof and have non-corrodible metal parts to resist the effect of sea air.

(2) The framework for securing the panels in position should be of angle iron and firmly supported.

(3) Compactness of arrangement of apparatus is very essential.

(4) Packing should be provided between the panels and framework to take up any inequalities between the panels and the angle-iron supports and to relieve the panels from strains due to vibration.

(5) Metal parts of the switchboard should be non-corrodible.

(6) Suitable means should be employed to prevent terminals and other parts from becoming loosened by vibration.

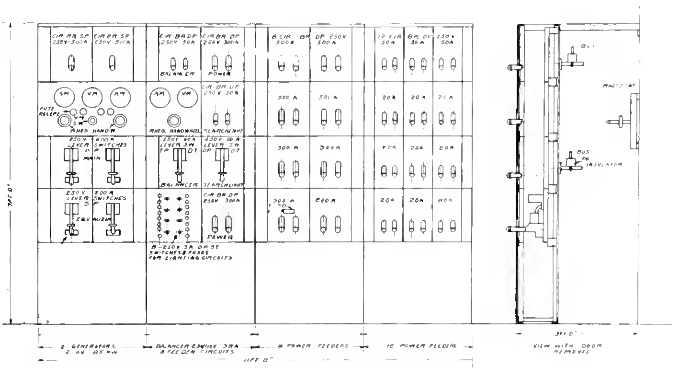

Fig. 2. A Dead-front Switchboard for Control of Two Auxiliary Generators and Balancer Set and for Distribution of Power and Lighting Aboard Ship

Auxiliary Distribution Switchboards of Small Capacity

On vessels where the auxiliary generators do not exceed 25 kw. capacity, the switchboard is comparatively simple.

Fig. 3 shows a view of a typical standardized panel which has been in general use for this class of service. These panels are suitable for the control of either one or two generators and a number of feeder circuits depending upon the requirements of the auxiliaries. They may be equipped either with air circuit breakers in the generator control circuit, as shown on the two-circuit generator control panel of Fig. 3 or with fused lever switches only. All equipment fully meets the requirements for sea service and conforms with the regulations of the American Bureau of Shipping.

The generator sections are standardized. There are only two layouts, one for the control of a single generator and the other for two generators. The radio and searchlight feeder circuits are always present on any of these vessels and are mounted on the generator section.

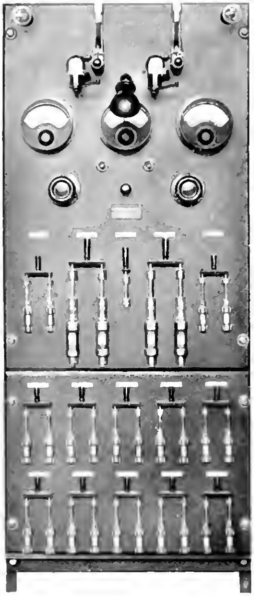

Fig. 3. Typical Auxiliary Distribution Switchboard for Small Capacity Circuits

Fig. 4 Safety-enclosed Unit Lever Switch

The feeder sections are also standardized and a section carrying the proper number of switches can be assembled with either of the generator sections.

The wiring connections in Fig. 5 are for two generators and twelve feeder circuits and are typical for panels of this type.

Safety Enclosed Unit Lever Switches Used on Vessels

Where line switches and fuses are required for controlling individual motors below deck at some distance from the main switchboard, the safety enclosed lever switch shown in Fig. 4 may be used to advantage. These switches may be mounted on bulk-heads, stanchions, or other places convenient to the motor.

The boxes are of heavy sheet steel and have non-corrodible finish. The switch cannot be closed while the fuse compartment is open and a cam on the operating handle prevents opening the fuse compartment when the handle is in the closed position. The switch is externally operated and the current carrying parts are completely enclosed and inaccessible while alive. The *on* and *off* positions of the switch are indicated on the box or cover.

Padlocks can be used to lock the switch in the open position and also to prevent the switch compartment from being opened except by an authorized person.

Inasmuch as the control of electrical circuits on board modern merchant ships has become so important, it is quite necessary that adequate switching facilities be provided.

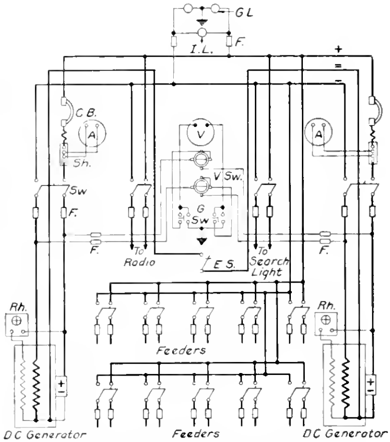

Fig. 5. Wiring Diagram for Control of Two Generators and Twelve Field Circuits, Typical for Type of Panel Shown in Fig. 3

The apparatus which has been described accomplishes this purpose and contributes in a large measure toward the successful operation of the other electrical equipment on merchant ships.

Electric Auxiliaries for Merchant Vessels

By C. H. Giroux

Marine Engineering Department, General Electric Company

In any industry there is a tendency to hesitate about adopting new developments that may eventually revolutionize existing methods. Nowhere has this been illustrated better than in the equipping of merchant vessels all over the world. On a large percentage of ships electricity is being used only for lighting and signaling. While such equipment is a convenience and contributes to safety it does not represent a saving to the owners except perhaps in lowering the insurance rate.

The other auxiliaries on these vessels are driven directly by steam and the apparatus in most cases is of a design that does not permit the use of its expansive properties. The losses due to radiation of heat from a system of this kind are enormous.

A manufacturing plant equipped in such a way would be very much out of date and would not be able to compete with a plant which takes full advantage of modern methods and apparatus.

In the present state of the electrical industry many intricate power systems are dependent upon an unfailing supply of electrical energy and any failure may mean a great loss of money, good will, or perhaps lives. The fact that such systems have been made possible is assurance enough to warrant the adoption of electricity on merchant ships. The Navy Department has for many years used electrical apparatus on war vessels, and there reliability is of paramount importance.

By observing proper precautions in the selection and installation of electrical equipment and by giving it the ordinary amount of intelligent inspection and care, no one need be skeptical about its successful performance.

There is great danger at the present time, however, when such applications are not generally understood, that apparatus not designed for marine use will be purchased by manufacturers of auxiliary machinery, by shipbuilders, or by ship owners. Such apparatus is very likely to give unsatisfactory service, and tends to create a prejudice against the general use of electricity on shipboard.

In choosing the auxiliary equipment the individual requirements of the vessel must be carefully considered in order to obtain the best results.

It is often possible to use the same kind and size of electrical equipment for a number of applications. This arrangement is desirable, because, in case of accident to one of the auxiliaries necessary to the operation of the ship, the equipment of one of the other units can be quickly substituted.

The type of propelling machinery used has a great effect upon the auxiliaries. For instance, the auxiliary equipment for a motor-ship will differ greatly from that of a steamship, and again there will be a difference between the auxiliaries of a ship driven by a steam turbine and those of one using a reciprocating engine.

In the case of the motor-ship, the advantages of electric drive for auxiliaries are more apparent than in the steamship but are none the more real.

As an example of the magnitude of the saving in the case of a motor-ship while at sea, there are given in Table I the results obtained on the *Benowa* and *Cethana*, the former equipped with electric auxiliaries and the latter with steam auxiliaries.

TABLE I

	Benowa	*Cethana*
Net registered tonnage	1788	1800
Propulsion	Two 500-h.p. Diesel Engines	Two 500-h.p. Diesel Engines
Average daily fuel consumption; main engines	1350 gal.	1365 gal.
Average daily fuel consumption; donkey boiler		557 gal.
Average daily fuel consumption; auxiliary engines	42.5 gal.	
Total daily fuel consumption	1392.5 gal.	1922 gal.
Per cent of total fuel used for auxiliaries	3.4%	29%

These figures show a saving of approximately 25 per cent in fuel consumption due to electric auxiliaries. Examination of the records of other ships shows a similar percentage gain.

The actual figures of steam consumption of steam-driven auxiliaries on steamships while at sea are very difficult to obtain because there is no ready way to segregate the auxiliary steam from that used for the propelling machinery. The best that can be done is to estimate the horse power requirements and choose a reasonable water-rate per horsepower hour. Taking a case typical of most steamships using electric drive or other economical propelling machinery, it is found

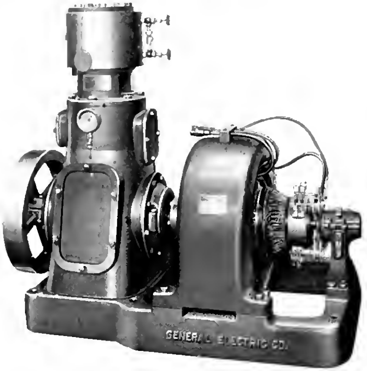

Fig. 1. Steam Engine Generator Set for Lighting Service on Moderate Size Vessels

that the steam consumption of the auxiliaries is about 30 per cent of the total steam used.

By properly choosing electrical equipment to replace the steam auxiliaries and by working out the most economical heat balance, it is possible to reduce the steam used for auxiliary purposes to less than 15 per cent.

Because the limited space allotted to this article does not permit of a discussion of the individual precautions to be taken in selecting, installing, operating, and maintaining electric auxiliaries, the importance of these factors must be indicated by the statement that they may spell the success or failure of any installation.

Generating Plant

On steamships where only a small amount of power is required, as for lighting, etc., steam engine driven generating sets have been very popular. Usually two of these have been installed on each ship so as to provide a spare unit. A modern unit of this type is shown in Fig. 1.

On ships carrying considerable electrical equipment, compact units of large capacity and high efficiency are necessary. These are turbine driven on steamships and oil engine driven on motor-ships. An auxiliary turbine-generator unit suitable for shipboard installation is shown in Fig. 2, and a representative oil engine generating set for use on a motor-ship is shown in Fig. 3.

Switchboards

A description of some of the modern switchboards developed for controlling electric auxiliaries is included in the article of P. J. Whitmore in this issue.

Pumps

Without going fully into the merits and uses of the various kinds of pumps which are on the market, it is sufficient to say that centrifugal pumps are the best adapted for electric drive and they should be used wherever possible. These pumps can be run at a relatively high speed direct connected to small motors, thus eliminating gears. Pumps of this character can be throttled without overloading the motors and without danger of injuring the equipment from high pressure.

There are applications on every vessel where, due to requirements for high pressure or high suction heads, reciprocating pumps are necessary. These are geared by a single or double reduction to motors running at moderate speeds.

Gear or rotary pumps have proved very valuable for some uses on shipboard. In the small sizes these are usually designed to run at a sufficiently high speed for direct connection to the motor.

Pumps which run at constant speed should be employed wherever possible. While it is

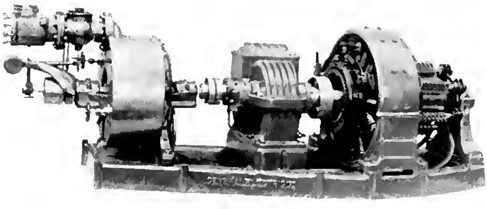

Fig. 2. Compact Efficient Turbine Generator Set for Vessels Carrying Considerable Electric Equipment

perfectly possible to provide motors with speed control, this feature in most cases increases the size and cost of the motor and complicates the control apparatus.

For driving pumps under the severe conditions encountered on shipboard, motors of the type shown in Fig. 4 have been developed. These operate on direct current, are enclosed, and are self ventilated. The air is drawn in at the commutator end through a cowl and discharged through the involute at the coupling end by a radial fan.

Screens placed over the ventilating openings prevent foreign material from being drawn in when the motors are in use and keep rats from building nests and gnawing the insulation if the motors are out of use for some time.

The hinged doors on each side give easy access to the commutator and brushes, but when closed bear against rubber gaskets, thus keeping out water.

The bearings of these motors are designed to operate continuously when the motor is tipped, at an angle of 15 deg. in any direction, without spilling oil or overheating.

The insulation is made practically impervious to moisture; and all small parts are made either of non-corrodible material or rendered non-corrodible by sherardizing.

A very important application on tank vessels is the cargo oil pump. Here the problem of electrification is complicated by the danger of igniting the oil vapor by sparks from the motor or control apparatus. For this reason a number of ships have been equipped with squirrel-cage induction motors. In some cases these have been located in the pump rooms directly at the pumps; in others, they have been located above deck and connected to the pumps by shafting. In both cases the control equipment has been located in the engine room, the ammeters being relied upon to indicate the performance of the motors.

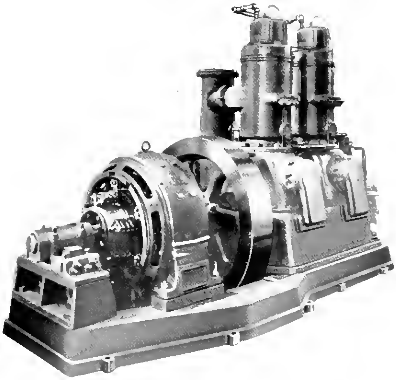

Fig. 3. Oil Engine Generator Set Designed for Service on a Motor-ship

On a number of vessels recently built direct-current motors have been installed in the pump rooms. Fresh air is forced through the motors by motor-driven ventilating sets above deck. As there is a positive pressure on the interior of the motor, explosive gas cannot enter and be ignited by sparks at the commutator.

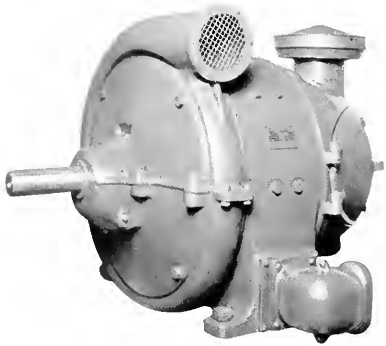

Fig. 4. Direct-current Pump Motor Designed Specially for Use Aboard Ship

The control equipment is located above deck in a specially constructed, well ventilated room, and is so interlocked that the cargo pump cannot be started until the blower is up to full speed.

The control for pump motors may in general be either magnetic or manual. While the magnetic control operated by push buttons is very convenient for the operator, much may be said in favor of the simplicity of manual control for motors of small power.

Air Compressors

On motor-ships, the air compressors which supply the starting, maneuvering and fuel injection air make up a very important part of the auxiliary installation. For small compressors the same type of motor is used as for pumps. For large sizes running at low speed, a pedestal bearing type motor resembling the auxiliary generator is used.

It is very often desirable to control the compressors from the main engine operating station by means of start and stop push buttons. If full pressure is maintained on the pistons of all stages, the required starting torque is very high. To reduce this torque, a magnetic unloading valve is employed where automatic control is used. This valve is usually connected to the inter-cooler between the first and second stages. As soon as the motor is shut down the valve bleeds the first stage to atmosphere. As long as the motor is running the valve remains closed.

Where required, automatic pressure regulators may be used to start and stop the compressors so that the pressure will always be maintained within a few pounds of a predetermined value.

Refrigerating Machinery

The refrigerating plant of a ship handling general cargo is usually of only sufficient capacity to take care of the galley requirements. This may consist of one or two units of one or two tons capacity. On refrigerating ships, the plant may run as high as 60 tons capacity and require about 200 horse power for the compressors alone. In addition to the ice machine proper, brine and water pumps are required as well as a number of fans for circulating the cold air through the cargo spaces.

A plant of this kind can be operated very economically by using electric power, and the space and weight will be materially less than that for steam equipment.

Steering Gear

The steering gear of a vessel must be made absolutely reliable. Therefore, no sacrifice of this feature must be made in favor of any other desirable characteristic.

There are two fundamental types of electric steering gear on the market at the present time, each possessing distinct advantages over the other.

In one system a high-pressure pump is used to circulate oil through a pair of opposed hydraulic rams, the plungers of which are connected to the rudder stock by a yoke. To move the rudder, oil is forced into one ram and removed from the other. A reversal of the oil flow causes the rudder to move in the opposite direction. When the rudder is at rest, there is no circulation of oil through the rams. With this type of gear, the pump is driven continuously in one direction by a shunt-wound motor. The control consists only of a starting device for the motor. The motor and control used is of the same design as that for other pump service.

In the other system, the electric motor is connected to the rudder stock by screw or spur gearing. As the motor is started and brought to rest for each movement of the rudder, it must be constructed for severe starting, stopping, and reversing duty. The control must also be able to withstand very frequent operation without rapid deterioration. Since it is imperative that the rudder be brought promptly to rest as soon as the motor is de-energized, dynamic braking in the *off* position of the control is desirable. The motor is compound-wound and has a predominance of the series characteristic. In addition to dynamic braking, it is sometimes necessary to use a solenoid disk brake to assist in bringing the motor to rest.

The same type of motor is used for this application as for the deck winches and anchor windlass, except that some of the waterproof features are omitted.

Forced Draft Blowers

If the motors for driving forced draft fans are installed where the heat from the boilers does not reach them, the same type can be used as for other engine-room auxiliaries. If it is necessary to subject the motor to an external temperature of more than approximately 50 deg. C., special heat-resisting insulation is recommended.

A certain amount of speed regulation is desirable so that proper draft can be obtained with the least expenditure of power.

Heating

A theoretical analysis of the losses involved in converting heat derived from the burning of fuel into electrical energy, and then back into heat, indicates that electric heating is not economical. How near the actual results approach theoretical calculations depends upon the magnitude of the losses which occur in transmitting the heat from the place where it is generated to the place where it is required.

Obviously it would not be economical to use electric heaters on a steamship where the state rooms are close to the source of steam supply. There may be places, however, at the extreme fore and aft ends, or on the bridge, where the losses resulting from long runs of steam piping may warrant the use of electric heaters.

On a motor-ship, if a separate boiler is contemplated for heating purposes only, the matter of electric heating should be carefully considered. Aside from the matter of efficiency there is the convenience of electric heaters to be considered.

A system of steam heating and ventilation combined is applicable to dining rooms and other large spaces on passenger ships. Low-pressure steam is led through numerous coils surrounded by a chamber through which fresh air is forced on its way to the registers. The air is supplied by motor-driven fans located preferably on the intake side of the heater.

Ventilation

The proper ventilation of a large passenger vessel is a complex problem involving the use of a large number of comparatively small motor-driven ventilating fans, located in various parts of the ship. On a cargo ship comparatively few sets are required as only a small portion of the interior is inhabited.

Motor and control apparatus for these sets do not differ greatly from that used for centrifugal pumps, as the power requirements are similar. It is usual to provide about 25 per cent speed adjustment by field control, so that the amount of air delivered can be regulated to suit varying conditions.

Lighting

Assuming that 230 volts has been chosen for the power system, the following alternatives are possible for lighting purposes:

1. Lamps designed for 230 volts.
2. Two 115-volt lamps in series.
3. Three-wire generator.
4. Separate generating set.
5. Motor-generator set to obtain low voltage.
6. Balancer set to obtain 115 volts.

A number of vessels are in operation using lamps designed for 230 volts. While these installations have been successful it is doubtful whether conditions warrant the general use of the high-voltage system. It has been found by careful investigation on land installations that the cost of maintaining high-voltage lamps is approximately 30 per cent greater than that for low-voltage units. This is due somewhat to the higher price of 230-volt lamps but mainly to the shorter life.

There are also a number of objections to the use of two lamps in series. Unless the lamps are specially selected for this purpose, the inequalities in resistance will tend to shorten the life of one. Any crossing of the filament or short circuit of one lamp will promptly burn out the other.

These considerations, and also the fact that suitable series burning lamps are not easily procurable, make the high-voltage system inadvisable for merchant ship service.

The use of three-wire generators, while perfectly practical, increases the cost of the installation by quite an appreciable amount and also complicates the switching arrangement, especially where generators are operated in parallel.

The use of a separate generating set for lighting purposes is still more costly and the additional expense and complication will at once eliminate this method from serious consideration except for cases of emergency. Where an emergency generating set is installed above the load water line of the vessel, it is advantageous to make switching arrangements so that this set can be run at night in port for lighting purposes when all other machinery is shut down.

Where close regulation of voltage is required the motor-generator system possesses great advantages, because a speed or voltage regulator can be installed. However, very close voltage regulation is not required of the lighting system on a merchant vessel, and therefore a balancer set is preferable for it has better efficiency than a motor-generator set.

The balancer set consists of two identical direct-current machines each wound for one half the line voltage. These machines are directly coupled together and the armatures connected in series across the line. A neutral bus is taken off where the armatures are connected together and the lighting load is balanced as nearly as possible on each side of the neutral.

The only current which flows through the set is the running light current and the unbalanced part of the load. The set is made of only sufficient capacity to handle the maximum unbalancing, and therefore with but little foresight in designing the lighting system, the balancer set can be made very small even though considerable power is required for lighting, galley appliances, searchlights, etc.

Miscellaneous

The auxiliaries referred to in this article and in that by Mr. R. H. Rogers do not comprise all that can be economically operated by electricity aboard ship, but space limitations in this issue of the REVIEW do not permit of their description.

Electric Deck Machinery

By R. H. Rogers

Marine Engineering Department, General Electric Company

Efficiency is a complex characteristic, especially when applied to the performance of machinery. The ratio of input to output is the component of efficiency most often discussed, so much so that other members of at least equal importance are often overlooked.

There is "readiness-to-serve," measured by the amount of care and expense necessary to keep it at a satisfactory percentage.

There is "continuity-of-service," also measured in terms of care and cost of holding at a satisfactory status.

"General fitness" must not be overlooked for here the human element enters into the equation. If the unit is offensive to sight, as incongruous or odd; to the hearing, as unmusical or antirythmic; to the feelings by way of uncomfortable heat, barked shins and knuckles, muscular strain or general unhandiness it will be condemned out of hand however near to 100 per cent the other components may be.

The relative weights of these elements vary greatly with specific applications of machinery, a point well illustrated by the varied functions of ship's auxiliaries. Take the steering gear as a whole—from the navigating bridge to the tumbling wake—it is on the shift from two to ten times a minute day and night for weeks. It works a million times (a favorite break-down test goal) in less than six months with only a few intervals for inspection and overhauling.

Readiness to serve here reaches supreme importance, for should it fail once in that six months a disaster might easily result, while at the least it would invoke the inverted blessings of officers and crew. Yet, 99.999 per cent is a respectable efficiency. The commonly considered input-output efficiency is rightly given scant consideration for there are popular types of steering gear ranging from 13 to 72 per cent mechanical efficiency and thermal efficiency of even greater range, with no apparent effect upon the number of each kind in use or on order.

Warping and mooring capstans or winches must be fit for the service. There is ample time to keep them in order as they are used only a few hours a year, and in the event of failure the cargo winches stand by to take the lines. Their only excuse for being is that they are advantageously located and are peculiarly adapted for the work.

With cargo winches, continuity of service is the strong consideration among the efficiency members. They are called upon to work eight to twenty hours a day from ten to thirty days at a time, totalling about 1200 hours per year. Like the Arkansas roof, when in port there is not time to overhaul and while at sea "who's going out on that deck in this weather?"

Used and abused by kaffirs, coolies, lascars and regular longshoremen, many taught in five minutes by signs, rigged and re-rigged to suit the varying practices of the world's ports, worked in all the temperatures on the thermometer—it must be a husky unit to give continuous service.

Each hold has its winches with no handy understudies so that the failure of a single winch holds up the work on perhaps 25 per cent of the cargo, breaks up the routine, throws the ship out of trim, and causes a delay the cost of which can only be appreciated by those who have had to pay demurrage on ships.

The anchor windlass is valuable in proportion to its readiness to serve. Dead for perhaps two thousand hours, it must come to life and work most heartily for a half hour and then hibernate again. These long periods of idleness are especially detrimental to machinery at sea. The input-output efficiency is so low in any case, due to the great gear reduction and the 50 to 60 per cent loss at the hawse pipe, that it is scarcely worthy of consideration—especially in view of the very few hours of service per year. Yet the function of the anchor windlass is vital to the safety of ship, crew and cargo, and there is no standby.

There is no form of motive power that can compare with electric motors for operating a plurality of widely scattered units such as are found on a ship. When properly incorporated with the respective mechanisms, the compactness of the set and the absence of visible moving parts appeal to the mechanical eye. The simplicity of lubrication, absence of unbalanced forces, small number of active parts and bearings, make possible a high degree of readiness to serve and of continuity of service with moderate attention and almost no cost.

The input-output efficiency of a battery of ship's auxiliary motors in terms of fuel used in port is for various reasons four times better than that of a similar battery of small steam engines. This is proved by the records of otherwise sister ships in the same ports with similar cargoes.

The fact that on a motor ship having all-electric auxiliaries the fuel consumption in port is one ton of oil per day as against four tons for the all-steam, and the knowledge that the most of this difference is due to innumerable losses, demonstrates that a large saving can be effected in such ships by substituting electricity for steam. Its adoption for all sea and port auxiliaries would eliminate various uncontrollable losses inherent in steam power, especially when finely subdivided.

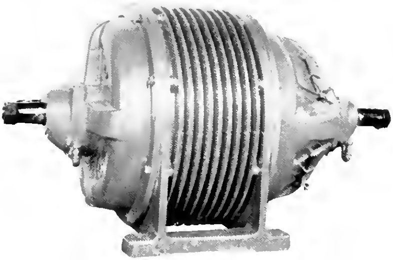

Fig. 1. Alternating-current Deck Motor Recently Installed on the Mooring Winch of a Tank Steamer

Many of these steam losses are a constant factor throughout the useful life of the ship. The larger part of the possible improvements may be realized in the distribution and applications of power, at the same time retaining the steam-driven generating plant.

The greater economy makes possible on steamships the use of an auxiliary boiler in port, thus still further improving economy. It does not require any argument to show the large gain that can be realized by operating a boiler of approximately 200 h.p. with its proportionate attendant auxiliaries instead of one of the ship's 1000-h.p. boilers at a 200-h.p. output with its relatively large but much under loaded attendant auxiliaries.

The reasons for the consumption of four tons of oil per day by the all-steam auxiliary ship as against one ton for the all-electric are readily analyzed:

(a) Loss by radiation from superheated steam in hundreds of feet of exposed piping bristling with flanges, special bends, valves, and fittings is going on every hour of the day, while electric distribution losses are microscopic when the units are in use and non-existent when they are still.

(b) The units are engined or motored for maximum demand and the average loads are therefore fractional. Motor efficiency is higher than engine efficiency throughout the load range, particularly so at fractional loads.

(c) Steam valves and packings deteriorate with time and use. Steam leaks take an ever increasing toll. Electric motors and distribution are unchanging through years of service.

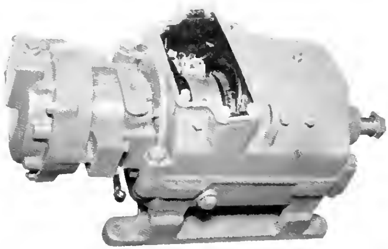

Fig. 2. Direct-current Deck Motor with Disc Type Solenoid Brake, Hand Hole Cover Removed for Inspection

(d) Frost has no effect upon motors and cables while steam deck auxiliaries require a large amount of steam during cold weather to prevent destruction by freezing.

(e) While in port the legitimate functions of auxiliaries are two: to handle cargo and to make the ship habitable. All other auxiliaries are parasites and they are greatly reduced or absent with electric power.

(f) A technical writer has recently said that one may see a steam leak, hear an air leak, and smell a gas leak, but there is no way to detect an electric leak. He may refer to a misapplication or wasteful system, for surely an electric leak, as such, is not a modest violet. It can be seen, heard, smelled, and felt as we all know and thereby it encourages a higher degree of upkeep than is the usual condition with less demonstrative mediums.

(g) Electric auxiliaries by greatly reducing the steam demand make it economical to use a small boiler operated at a high efficiency for the normal demand, thus avoiding the excessive losses of a larger boiler operated at fractional load.

The hard trying service on shipboard brings out the value of the accessories of electric drive, i.e., the brakes and braking system, control, protection, indication, and distribution.

The solenoid brake provides an automatic holding device independent of the human element. It is electrically released whenever the motor is running under power, and gravity or spring applied whenever the current is cut off whether by intention or accident.

To lower a load at a constant speed dynamic braking may be resorted to, wherein the motor becomes a generator overhauled by the load. The mechanical energy developed by the load is converted into electricity and dissipated as heat at the resistor. In other words, electricity is used as a pair of tongs to carry to a safe distance from the moving parts the heat generated by braking a descending load.

The control of electric motors is independent as to location; the machine and the controller may each be located to the best advantage. The full range of speeds in both directions, retardation, and stopping are controlled by one handle.

Protection from sustained or excessive overloads and prevention of unexpected starting after power has been off are obtained by simple devices which may be located at will, for whenever the control handle is returned to "off" the devices are automatically reset for operation, i.e., the operator does not have to leave his position as would be the case with ordinary devices.

The working condition of any electric power unit or the power consumed by any set of machines for any period may be read upon portable or fixed meters. Abnormal conditions are immediately noticeable where a running log of power consumed is kept by a recording meter.

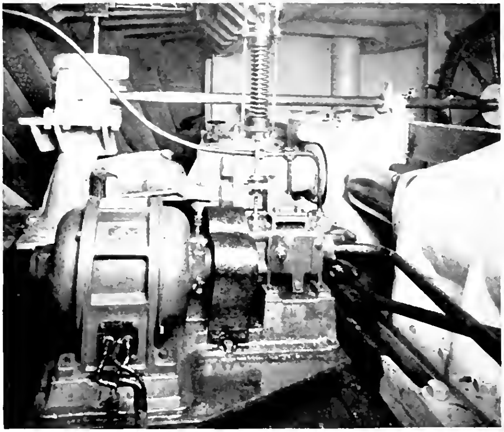

Fig. 3. Alternating-current Motor Operating Hydraulic Steering Gear

The distribution of electric power on a ship is simplicity itself as compared with steam power distribution. Steam requires a system of large pipes, supported in stools on deck, protected by an elaborate system of plating, and made to conform by innumerable special bends, flanges, valves, and fittings. The deck is much obstructed, constant losses occur through radiation, and destructive freezing of condensate may occur in cold weather.

Electricity is distributed through flexible cables of a fourth the cross-section of equivalent steam pipes. They are carried underdecks

TABLE

DECK AUXILIARIES

Auxiliary	No. of Units	Duty	H.P.	Geared	Brakes	Dynamic Braking	Protection	Control	Resistor
Anchor Windlass	1	Very intermittent. Severe. Long periods of idleness, often submerged.	35 to 75 30 min.	Triple spur or worm and spur.	Clutches. Mechanical brakes. Solenoid brake on motor.	No	Line switch. Overload relay. Low-voltage contactors, arm. res. for stalling at 100% torque.	Manual drum controller or contactors and master switch.	Starting and stalling
Cargo Winches	2 to 32	Fast cycles. Severe duty. Idle at sea and sometimes submerged.	25 to 35 30 min. or 1 hr.	Double spur and two speeds by gear shift. Drum and gypsy or worm with gypsy only.	Solenoid on motor. Sometimes foot brake or automatic mechanical brake.	Yes if not foot or automatic	Line switch. Overload relay. Low-voltage contactor reset by controller.	Manual drum type water-tight.	Starting and dynamic braking
Capstans	1 to 4	Intermittent Moderate. Long periods of idleness.	25 to 60 30 min. or 1 hr.	Worm or spur gear and worm.	Seldom used. Sometimes solenoid brake on motor.	No	Line switch. Overload relay. Low-voltage contactor. May have arm. res. to stall at 100% torque.	Manual drum type.	Starting and perhaps stalling.
Steering Gear	1	Fractional load 2 to 10 per min. seldom fully loaded.	15 to 45	Direct connected to pump and running continuously, or geared spur and screw to rudder and starts with each move.	None if direct-connected to pump. Solenoid on motor if geared to rudder stock.	Yes if geared	May have overload and low-voltage but protection is considered undesirable.	Starter only if hydraulic. Master switches and contactors if geared.	Starting and if geared dynamic braking.

and require no separate covering. The first cost of the parts and the cost of installation are in favor of electric distribution.

The necessary resistors for starting all the motors, for braking the winches, and for safely

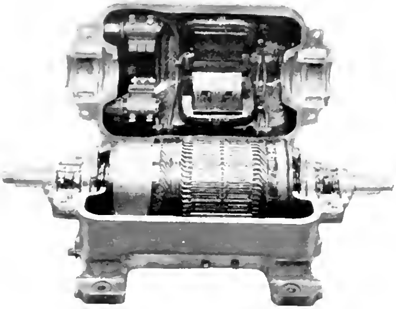

Fig 4. Direct-current Deck Motor, Upper Half Opened Back on Its Hinges

stalling the windlass and capstan motors are most economically housed by the shipbuilder below deck where possible, or in enclosures under the boom tables, or in special structures for the purpose. They require good ventilation when in use and must be protected from sea water. Space is required for access and for removal of the units. With each group may be located the protective panel and the line switch so that any motor may be disconnected for inspection.

Motors for ship's deck auxiliaries must be designed expressly for the service; strong, tight, without loose parts, and able to stand up to the hardest work without immediate or accumulative deterioration.

The strictly electrical parts throughout must be designed to withstand the conditions peculiar to the sea and ships. Neither lubrication nor actuation of movable parts must be affected by the rolling or pitching of the ship. Every item must be able to withstand shocks and stresses not experienced by land equipment. All insulated wires, whether cables, external coils, armatures, fields, or connections must rigidly be fortified against the cumulative invasion of moisture which is particularly persistent at sea where salt assists by attracting atmospheric moisture.

Enclosures such as motor frames, brake coils, housings, controller cases, resistor and panel structures must be built to exclude water as such, and to release moisture that may have condensed to water within through temperature changes.

Brass, bronze, copper, iron, and steel must be consistently protected against the corrosive effects of salt moisture, and electrolysis must be guarded against.

The heating of motor grids and brakes must be kept within allowable limits by the selection of types and sizes to suit the heaviest anticipated duty under the most adverse circumstance.

The wear and tear on the brakes, the motor heating, and the accumulated loads thrown on the generators by a battery of winches are dependent to a considerable extent upon the flywheel effect of the revolving parts, especially when reversals are occurring at high frequency as when handling case oil. Low speeds, small diameters, and light weights are the specifics for these items.

The mechanical designs of motor-operated deck machinery are well worked out and have been in active service at sea for many years. Reference to the catalogs of builders will reveal, in the broad range of choice presented,

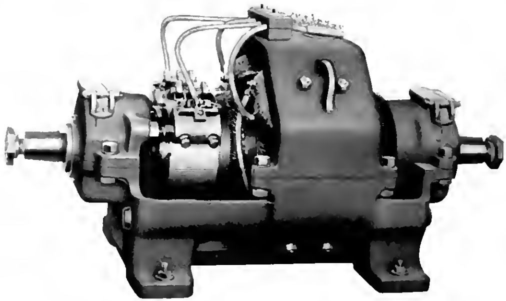

Fig. 5. Open Type Direct-current Motor for Below Deck Installation

the compactness and general appearance of fitness previously mentioned.

Table I shows the characteristics of the various deck units.

Layout, Construction and Installation of Propulsion Equipment and Auxiliaries for Marine Drive

By C. M. Rhoades

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The overall efficiency and life of the main propulsion equipment is largely affected by the layout of the engine room, the construction of suitable foundations, and the proper installation of auxiliaries, piping, cable, and control; and this article is written to point out the most important features that should be kept in mind in arranging an engine room either for turbine-electric drive or turbine-gear drive.

In arranging machinery in the engine room there are of course several fixed conditions. As in the case of single-screw ships the motor or the turbine-gear unit has to be placed on the center line of the ship and at an elevation to suit the propeller shaft.

There are, however, a number of auxiliaries which, while they are independent of the main unit, should be given considerable thought in connection with the service to which they are to be applied, their location, accessibility, and proper installation.

The system of turbine-electric drive has more flexibility in the placement of machinery than any other type, as the turbine generator can be placed amidship with the boilers while the motor can be placed aft. The turbine generator can be placed on the side of the center line of the ship, or can be placed over the condenser; either arrangement has arguments in favor of it, depending on the design and class of the boat.

In cargo boats with full lines a very economical arrangement is to have the turbine generator amidships with the boiler room and motor aft, thereby saving considerable engine-room space, shaft, and shaft-alley, and eliminating the obstruction of the shaft-alley in the cargo space.

Figs. 1 and 2 show an arrangement of a 3000-s.h.p. engine-room and motor room that would be suitable for cargo ships having the engine room amidship and the motor placed aft. Fig. 1 gives an idea of the flexibility of the turbine-electric drive arrangement, as the turbine generator can be placed well up in the ship so as to take advantage of the space over the boilers and this reduces the length of the engine room.

This scheme of having the main unit elevated, which gives two or more flats, requires the minimum amount of cubical space as it not only cuts down the length of the engine room but also the width and keeps the machinery away from the ship's sides, thus giving additional bunker or fuel oil space, and in turn giving more cargo space for a given ship tonnage. There would naturally be space required back of the boilers and this could be carried to the ship's sides, in way of the engine room, which space could readily be arranged to take care of any inlet or discharge piping from sea connections.

The engine room as shown in Fig. 1 is based on using electrically driven auxiliaries and just enough steam units to maintain a proper heat balance. The only steam-driven units are the turbine-driven exciters, the standby oil pump, fire and bilge pump, auxiliary boiler feed pump, and the steam air ejector on the main condenser; all other auxiliaries are of the motor-driven centrifugal type.

The main turbine generator, the two auxiliary direct-current turbine generators, and the control panel are located on the upper flat convenient to the engineer on watch. The condenser is carried directly below the turbine, which is the most efficient location and insures the turbine casing being drained at all times. This arrangement possesses a decided advantage over that of top exhaust units where the proper drainage of the turbine casing has been neglected and the life of the turbine unit been reduced by running turbine wheels in water.

This arrangement also eliminates the rather complicated exhaust trunk which is necessary in top exhaust units and also gives a very good distribution of weights, as the main unit and condenser are symmetrical about the center line of the ship. It is also possible to place directly beneath the operating panel, on a flat, the main contactors or switches for handling the current to the motor. These contactors can be either electrically or manually controlled from the operator's position, so that the engineer has

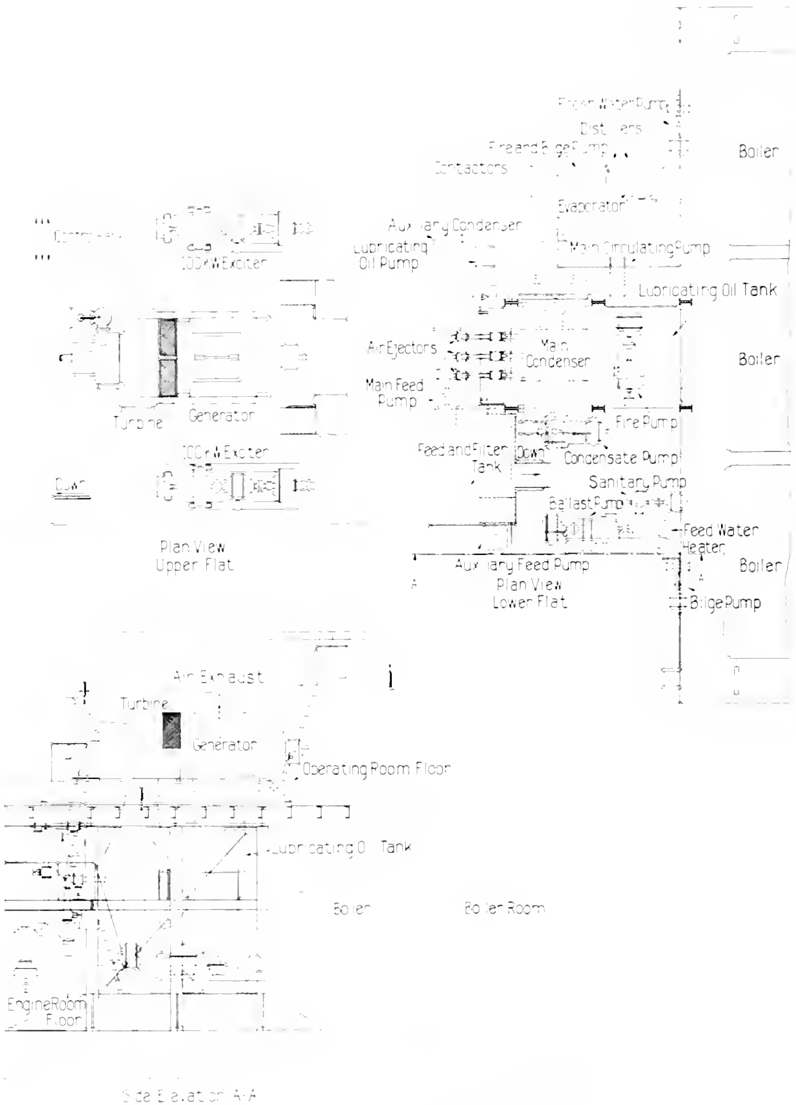


Fig. 1. Diagram Showing the Location and Arrangement Amidship of 3000 Shaft H.P. Turbine Generator Set and Equipment on a Vessel of Moderate Size

entire control of the propulsion equipment and the main turbine at the control panel.

On the lower or engine-room floor are located all of the ship auxiliary pumps which when motor driven can be compactly arranged, as all steam and exhaust piping, which is a large factor in congesting the engine room, is eliminated.

This arrangement also lends itself to very simple and safe wiring, as all the cables can be carried underneath the turbine flat where they can be well supported and protected and led directly from the generator terminals beneath the generators to the contactors and switchboard, and all wiring to auxiliaries can be carried overhead to the motors. With due consideration to placing auxiliaries on the engine-room floor, the arrangement could be made to be very free of piping and a safe and efficient room obtained.

The motor room as shown in Fig. 2 can be placed as far aft as the lines of the ship will permit, and still have a satisfactory foundation for the motor and ample room for drawing the tail shaft. The motor shown in Fig. 2 is arranged to have the thrust taken up in the forward end of the motor.

The wiring to the motor room may be carried either in a wiring passage at one side of the ship between engine room and motor room or may be carried above decks. The decks above can be covered, leaving only the necessary openings for access ladders and for air supply and discharge ducts. To provide

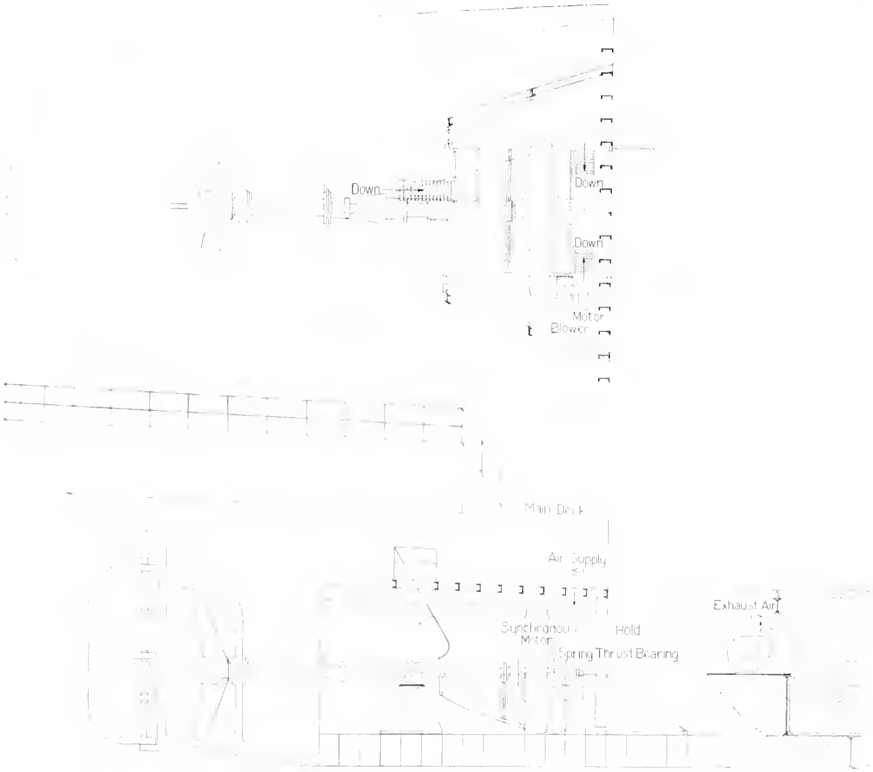


Fig. 2. Diagram Showing Installation of 3000 Shaft H.P. Propulsion Motor. The arrangements shown in Figs. 1 and 2 are related and apply to the same installation

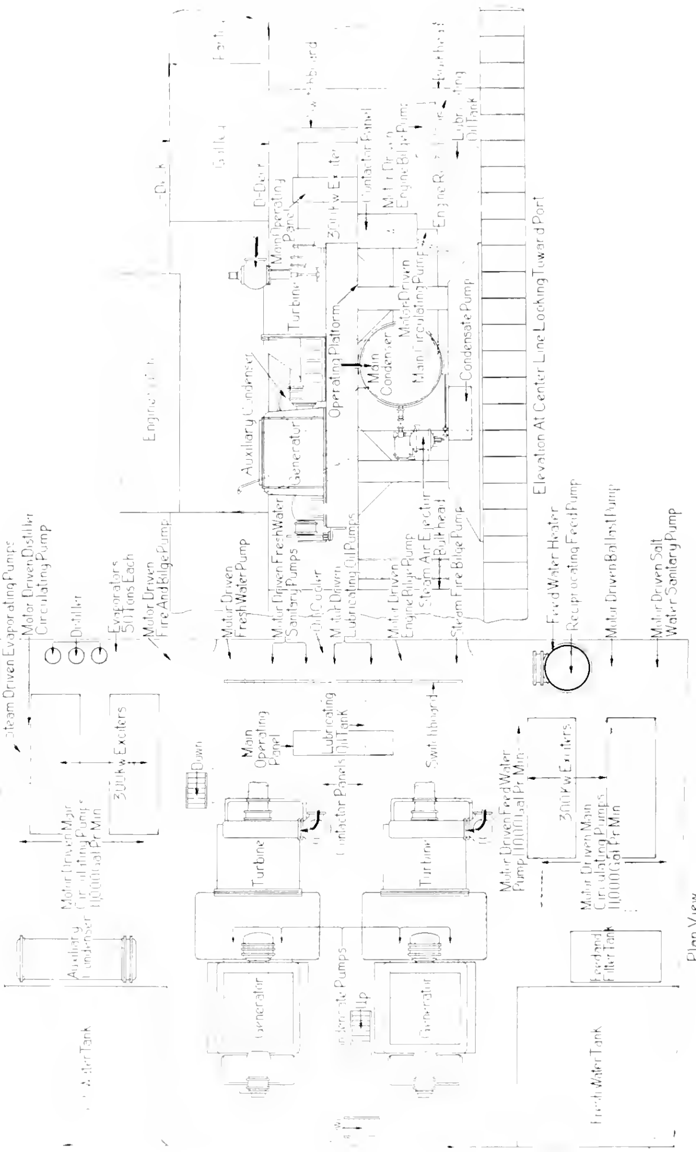


Fig. 3. Diagram Showing Arrangement of Engine Room Amidship for 30,000 Shaft H.P. Twin Screw Vessel

for the removal of a portion of the motor, a section of the bulkhead forward of the motor could be made removable and motor taken out through the cargo space and hatch.

Figs. 3, 4, and 5 show arrangements for a 30,000-s.h.p. twin-screw ship, Figs. 3 and 4 showing the engine room amidship and the motor room aft, while Fig. 5 shows the same equipment with motors in the engine room.

In both arrangements shown in Figs. 3 and 5, the main turbine generators and auxiliary generators, together with the control panel and switchboards, are all located on the upper flat convenient to the engineer on watch. The condenser and all auxiliaries are located on the engine-room floor beneath.

Practically all auxiliaries are electrically driven, there being just sufficient steam units to give the proper amount of exhaust steam for feed-water heating. In this arrangement, additional flexibility and insurance has been obtained by having two circulating pumps and two condensate pumps for each condenser. The engine room in both cases takes up the full width of the ship.

The saving in space by the arrangement shown in Fig. 3 as compared to that in Fig. 5 is self evident; the engine room would be 12 to 14 ft. less in length, which saving is of considerable value.

Fig. 4 shows the space required for the motor room aft. As previously stated, this motor room should be placed as far aft as the lines of the ship will permit, thereby eliminating as much shafting and shaft-alley as possible.

Fig. 6 shows an arrangement for a turbine-electric driven single-screw tanker, or any other ship in which all machinery is placed aft. In this arrangement the main turbine generator is placed down on the engine-room floor with top exhaust, and the only apparatus carried on the upper flat are the two auxiliary direct-current turbine generators. The same scheme of electrically driven auxiliaries has been carried out as in the other arrangements described.

In all arrangements of engine rooms, one should keep in mind the service and duty of each auxiliary because the proper type of drive, grouping, and arrangement will eliminate a great deal of duplication in piping, as the pumps that are to be interconnected to the same service should be arranged as closely together as possible. Also, all pumps should be kept above the engine-room floor

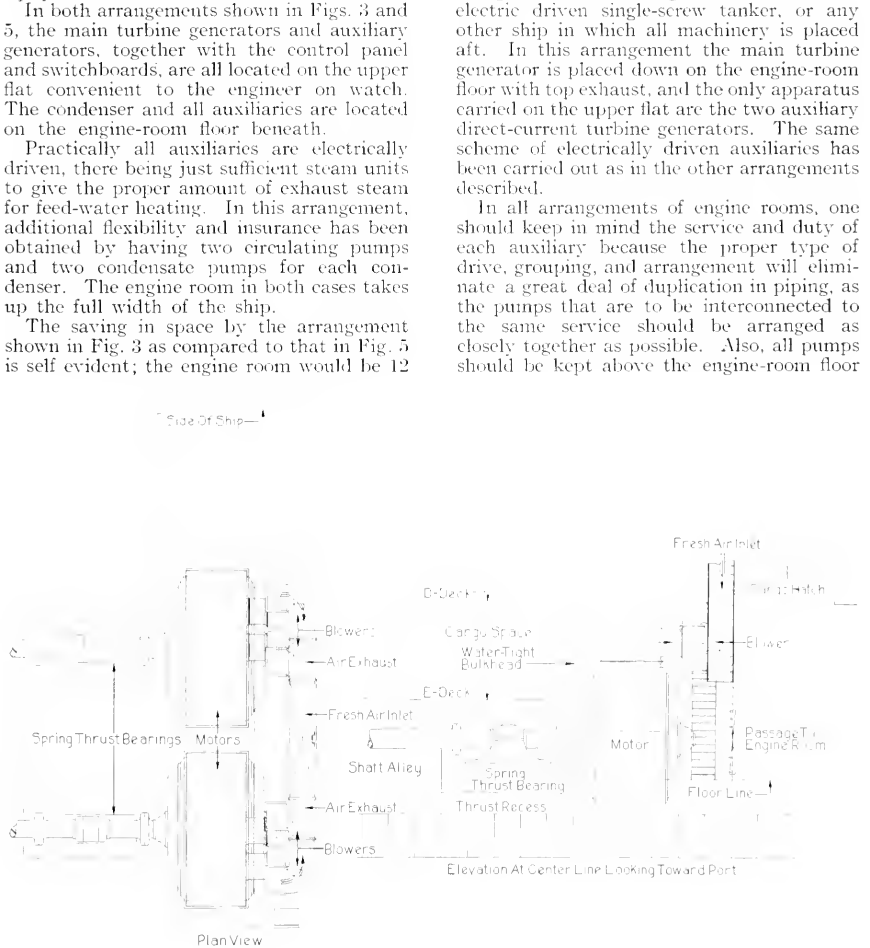


Fig. 4. Diagram Showing Arrangement of Motor Room Aft for 30,000 Shaft H.P. Twin Screw Vessel

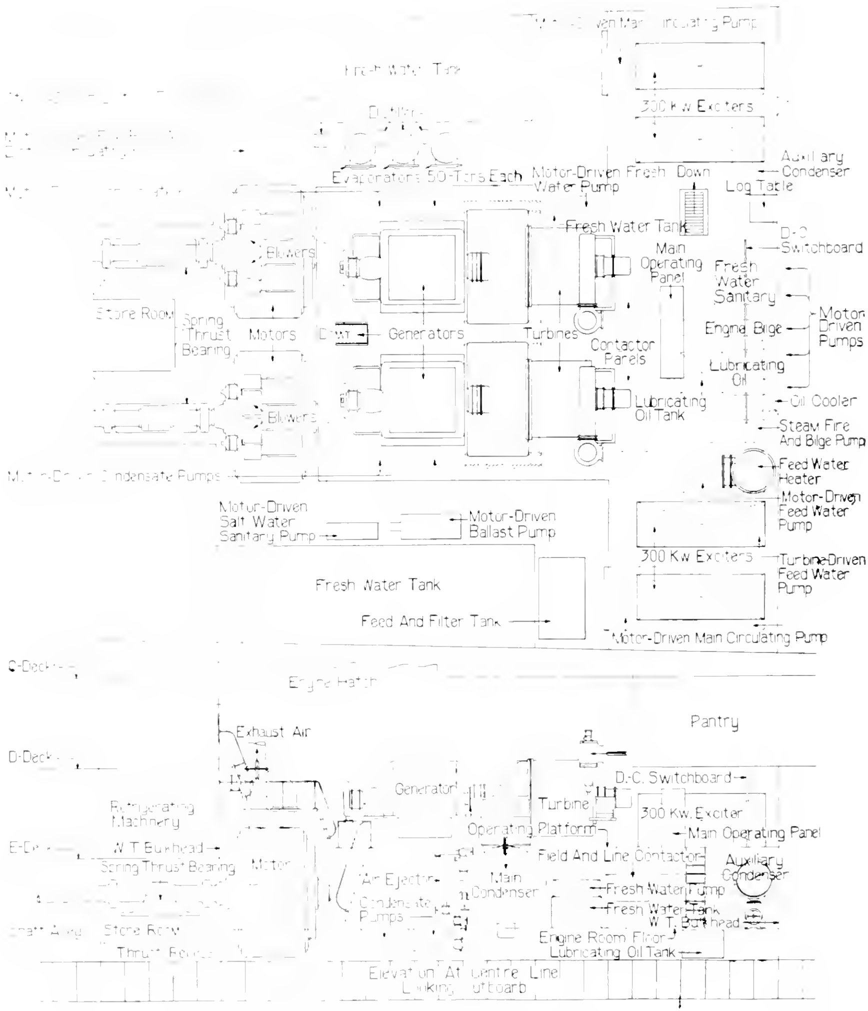


Fig. 5. Diagram Showing the Equipment of Figs. 3 and 4 Installed in the Same Compartment. This arrangement of apparatus occupies more space and is less desirable than that represented in Figs. 3 and 4

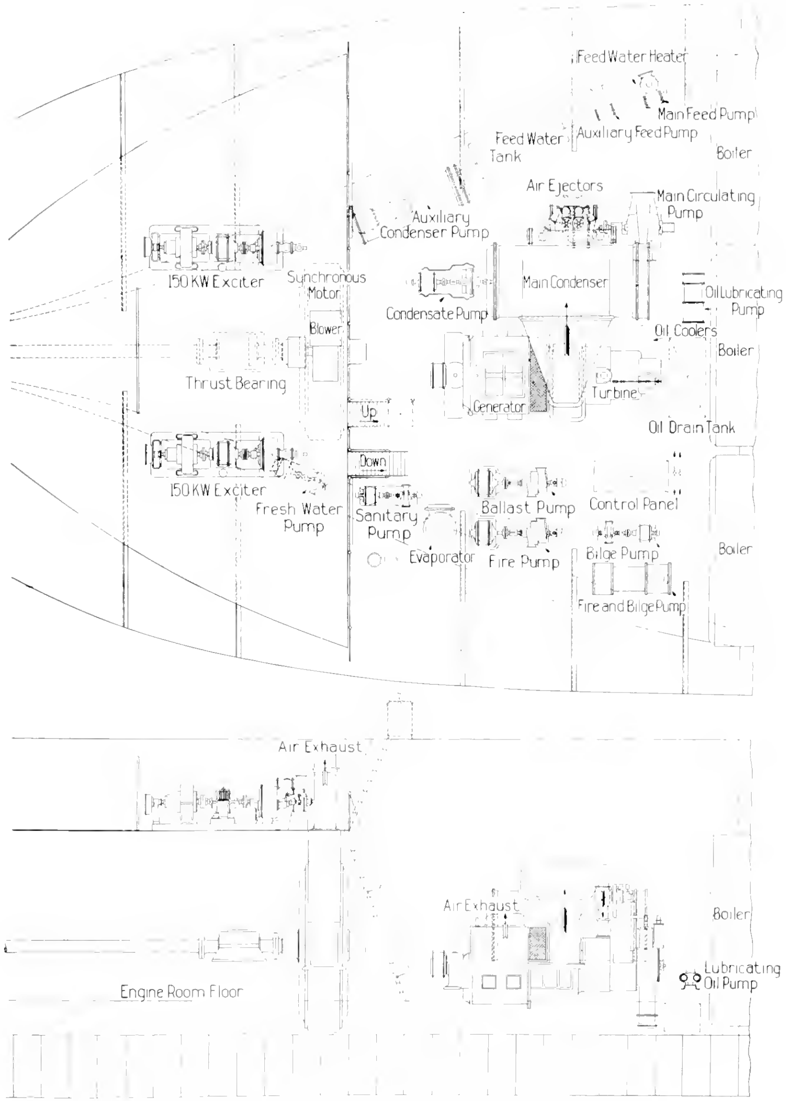


Fig. 6. An Arrangement of Turbine-electric Drive for Single Screw Vessel in which all Apparatus is Placed Aft

and be accessible, for the best safeguard for keeping a pump in satisfactory operating condition is to have it where a man can see it and readily get at all its parts.

The matter of proper foundations for marine turbine generators, motors, and gears is one that should be given very careful consideration, as the proper functioning and life of the equipment depends upon true alignment and keeping of this alignment under all conditions of service and operation.

Fig. 7 shows a typical foundation for a 3000-s.h.p. turbine generator, which could be placed on the upper platform as shown in Fig. 4 or on the tank top as shown in Fig. 6. This foundation consists of two fore-and-aft girders of sufficient depth to insure the after, middle, and forward bearing points being kept in line regardless of the working of the ship. The generator and turbine after foot is carried directly on the side girders, while the forward turbine foot is carried on athwartship plates framed into the longitudinal girders in such a manner as to carry the weight of the forward foot to the longitudinal girders and to also insure sufficient flexibility to take care of the expansion in the forward end of the turbine due to the changes in temperature of this portion of the unit.

When the turbine generator is carried on the tank top, this foundation should extend over as many frames as possible so as to distribute the loading and prevent concentration. When the unit is carried on the upper flat, a somewhat similar foundation should be placed under the turbine and also on the tank top, both of which should be properly framed to take care of the supporting columns. The girders are framed together at several points and are also provided with outside gusset plates to insure proper bracing against rolling.

The entire foundation is built up of plate and angles provided with rider plates in way of all bearing points, which plates should be ground off to facilitate the fitting of liners, which should be not less than $1\frac{1}{4}$ in. thick. All bolts for bolting down apparatus to foundations should be fitted bolts.

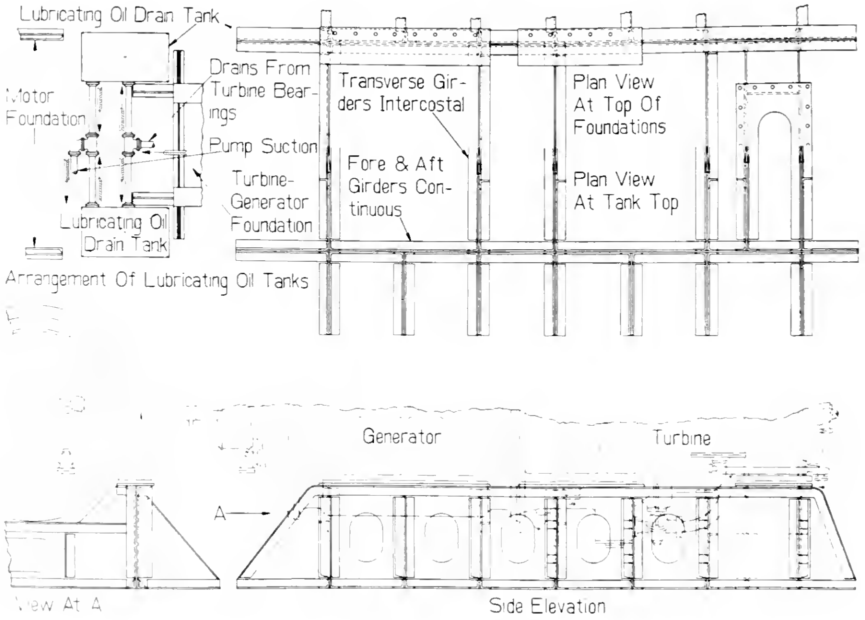


Fig. 7. Typical Foundation for 3000 Shaft H.P. Turbine Generator

A typical foundation for a 3000-s.h.p. motor consists of two fore-and-aft deep girders, one under each foot of the motor. The girders are well gusseted to the tank top and are tied together on the forward and after sides by means of plate work, which should form a water tight pit in which the motor sits. These plates on the forward and after sides should be made with a removable section to permit the drawing of the motor rotor.

As in the case of the turbine-generator foundation, the motor foundation should be distributed over as many frames as possible.

The engine-room piping should be simplified as much as possible by the proper grouping of units and by the leaving out of all unnecessary valves. The piping should be well supported and arranged to take care of expansion without undue strains on the fittings.

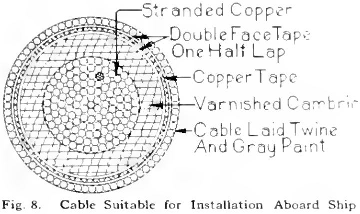


Fig. 8. Cable Suitable for Installation Aboard Ship in Locations Where There is no Likelihood of Flooding

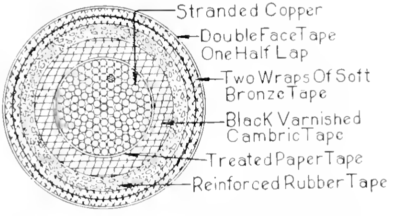


Fig. 9 Cable Similar to That Shown in Fig. 8, Except for an Additional Rubber Jacket to Protect It from Water

One of the elements of electric drive, which should be given careful thought in installation, is the proper type of cable and its location, together with its supports.

For all low-voltage direct-current cables the best type is a lead-covered iron-armored cable insulated with varnished cambric. It should not be run in conduit but should as far as possible be carried overhead where it can be inspected, well supported, and painted.

For the main alternating-current cables connecting the main generators, contactors, and motor, there should be supplied a cable having a good factor of safety, both electrical and mechanical.

Figs. 8 and 9 show two types of construction for alternating-current cables. Fig. 8 shows the type of cable that could be used when all of the machinery is placed in one engine room, and it would never be necessary to operate the cables when the space is flooded. The insulation on this cable is varnished cambric with a spiral copper tape placed over the cambric for mechanical protection. This tape is grounded so that it serves a double purpose as assurance against mechanical injury and the endangering of life, for should there be any leakage through the insulation to this metal sheath, which is grounded, the operator could meet with no injury due to accidental contact. Over this armor is braid and twine which is covered with a fire-proof paint.

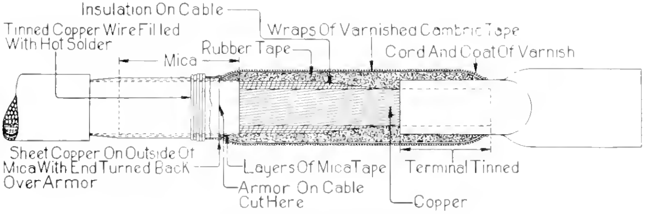


Fig. 10 Method of Attaching Cables to Cable Terminals to Prevent Entrance of Moisture into the Insulation

The cable shown in Fig. 9 is identical to that described in Fig. 8 with the exception that it has a rubber jacket placed over the cambric. This cable would be used when necessary to pass through other compartments than the engine-room space, so that should any intermediate compartment be flooded the rubber jacket would amply protect the cable against the water.

Both of the cables described are what is known as single conductor cables and are recommended for large current carrying capacities in preference to several smaller three-core cables in multiple.

In the carrying of these main circuits they should be given every consideration as to proper supporting and protection; they should be carried in such a manner as to eliminate all short bends and be protected against mechanical injury and should be well supported by means of insulating clamps. Their ends should be well protected against moisture seeping under the insulation. Fig. 10 shows the method of taking care of these cables where they are attached to cable terminals.

The General Electric Company makes a two-plane type of turbine reduction gear and several of these have been installed in place

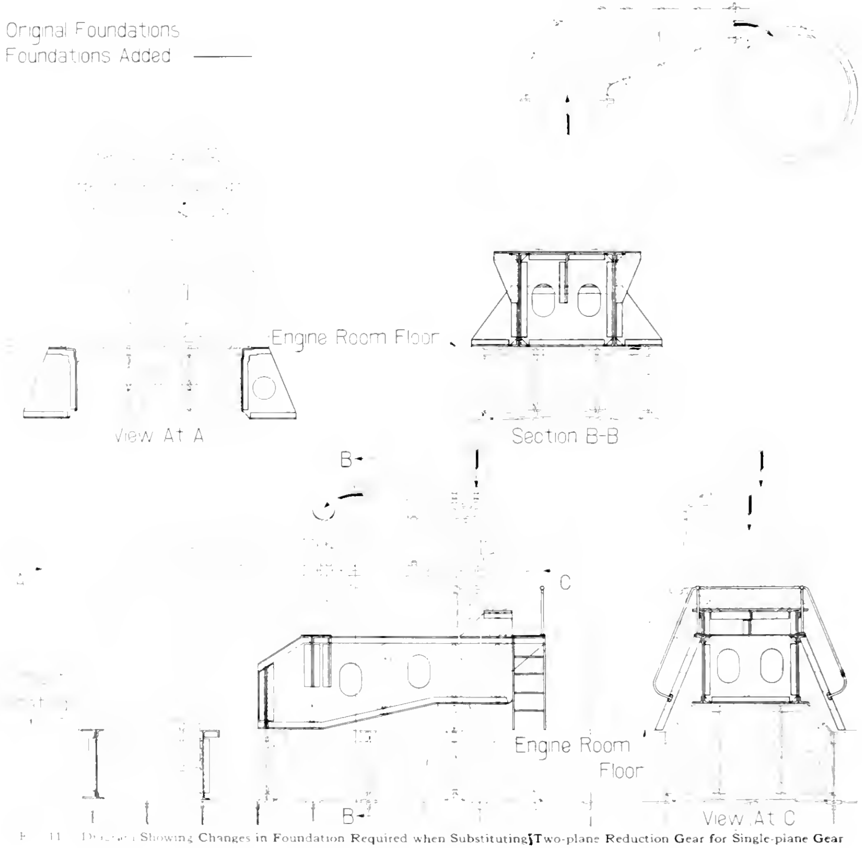


Fig. 11. Diagram Showing Changes in Foundation Required when Substituting Two-plane Reduction Gear for Single-plane Gear

of the single-plane type. Fig. 11 shows how readily this can be done with a minimum amount of work to the existing foundation.

The work to be done in making this change is the adding to the width of the foundation for the low-speed gear feet which are wider in the case of the two-plane type, the providing for the supporting of the turbine which has been raised approximately four feet, and a new exhaust trunk. The supporting of the turbine in its raised position is taken care of by a superseating structure which supports the forward turbine foot and the high-speed gear foot and is built up in the shop and attached to the existing foundation.

By actual experience, it is proved that practically all of this steel work for the superseating and exhaust trunk can be gotten out in the shops and assembled before the ship arrives; and this change from single-plane type to two-plane type of gear can be made in a very few days with naturally a corresponding minimum of expense. The turbine in its raised position requires the fitting of extension rods to the throttle levers if these are still to be operated from the engine-room floor, but this is readily done as shown in Fig. 11.

In all cases where this change has been made it has required very little work, if any, to the remainder of the ship aside from the foundation.

Marine Uses of Radio

By Adam Stein

Radio Engineering Department, General Electric Company

About twenty years ago, when first demonstrated that wireless communication was possible over considerable distances, it was immediately apparent that the invention would be of great use and value. It was obvious that communication with ships at sea, which was not possible by any other known means, would be an enormous aid to the convenience and safety of navigation. So we have seen the marine use of radio communication grow very rapidly, until now almost every ship on the seas carries radio apparatus. In the early days of radio, however, it was not apparent that it would find other uses than communication, and so it is rather unexpectedly that we find today that radio is not limited to communication but has other possibilities of use which approach communication in degree of importance, and which indicate that radio will play an increasingly important part in marine affairs of the future.

Of course the use of radio for communication has been the greatest one, and technical advances giving better communication possibilities have been rapid and great. It is the result of the development of new devices and methods for communication that the scope of radio has been extended beyond communication only.

The present communication uses of radio are quite varied. Foremost is the use in cases of distress. The large number of cases already on record of ships and lives saved by help summoned by radio proves the value and the efficacy of this service. Radio equipment is needed on every ship, not only to summon aid in case of need, but also to hear the distress calls of other vessels. The degree of safety provided by this means of summoning aid is enhanced by every addition to the number of ships "listening-in" on the seas, because thereby the chances of being heard are increased. Many ships, non-passenger carrying, at present do not consider it worth while to install radio, but doubtless the time is not far distant when radio will be considered a necessary part of the equipment of every ship, partly because of the possibility of giving, as well as calling for, aid.

Isolation of the ship at sea is slowly but surely disappearing under the effect of radio. No matter how far from land, ships can keep in close and immediate touch with the remainder of the world. It is no longer necessary to take even temporary leave of the world and its affairs when putting to sea, and of course this has a marked effect on maritime practice.

One useful result of the possibility of communication is that owners or shore directing offices can communicate with and control the movements of their ships at sea. The port of destination can be changed if desired or any other information concerning passengers, cargo, etc., transmitted to the captain of the vessel. The most extensive example of this was given at the outbreak of the world war when all German merchant vessels were advised of the declaration of war, and were instructed to make for the nearest home or neutral port. It is said that the value of shipping thus saved by Germany, although subsequently lost through other circumstances, was sufficient to more than pay the costs of the various high-power radio stations which she had erected in various parts of the world for this and other purposes. In the beginning of radio use, some ship captains resented this intrusion upon their supremacy at sea, but this feeling has been entirely overcome through appreciation of the advantages.

Equally important is communication from the ship to shore, particularly when nearing the port of destination. Then the ship can communicate its time of arrival, docking requirements, etc., and can be advised of the dock to which it should proceed, etc. This sort of communication is very valuable because it saves much time, and permits the arrival and docking of ships to become a smooth and well planned affair. The time and consequent expense saved in the docking of large vessels amounts, sometimes in a single operation, to the total cost of maintenance of the radio equipment for perhaps a year's time.

Various other navigational uses of radio have importance. One is the checking of ships' chronometers by time signals sent out daily from high-power land stations. At these stations definite signals are sent automatically, and with great precision, at certain hours daily. Since radio signals travel with the same velocity as does light, negligible error is found at any point at sea in checking chronometers by this method. Since accurate time keeping is essential to accurate navigation of the ship, this service of radio is very useful and is very extensively utilized. High-power land stations also give to ships the service of daily news items, which adds much to the comfort and benefit of both crews and passengers. Communication between passing ships is often of value for exchange of information on weather, supplies, etc. "Ships that pass in the night" are no longer unknown to each other—nor is the horizon limited to the few miles of visual or light signalling, for the radio horizon of a ship is extended to several hundreds of miles.

The use of radio for passenger communication to shore is the one most familiar to the public and needs little comment. As radio conditions are today, there is hardly a spot on the oceans from which messages cannot be sent to any other part of the world with assurance of delivery within a few days' time at the most—and most traffic is from points such that normal delivery is effected within the day.

Technical advance in radio has been great in the last few years in every branch of the art, resulting in at least two important advantages: First, communication has become more reliable and possible over greater distances. Second, telephony by radio has been made possible—the hopes and dreams of all radio workers realized. It is now possible to telephone by radio over any distance reasonably desired in ship service. This can be accomplished with the same degree of perfection that exists in radio telegraphy, and is not subject to serious handicap as is so often the case at first in radical innovations.

The marine applications of radio telephony which will be useful in the immediate future are: Ship to ship, ship to shore, and ship to land wire telephone systems. Ship to ship telephony will be limited mainly to communication between captains of vessels as an aid to the safety and convenience of navigation. Ship to shore station communication also will be limited mainly to the use of mariners for conference on weather conditions, docking instructions, etc., with their company offices ashore; and of course, the number of private stations of this kind which can be erected on shore will be very limited. Under this heading also comes communication from land to ship, from stations erected to send out spoken warnings of shore menaces to navigation. It is probable that many of these stations will soon be erected as adjuncts to lighthouses. Their value lies in the fact that they are entirely efficacious in foggy or stormy weather, when light warnings are less effective. Also, they can be understood on ships without the aid of expert telegraph operators.

Ship to land wire telephone line communication is the most important class of radio telephony. The modern radio telephone apparatus is such that it can be connected to the existing wire telephone system, thereby, in effect, making every telephone instrument in the country a potential wireless telephone station. When ships are equipped with radio telephone apparatus, and the details of the conjunction between the wire lines and the shore radio station are arranged, it will be possible for persons aboard ship to talk directly to any telephone subscriber ashore. It is expected that this condition will exist for service use in one or two years' time. A large extension of the usefulness of radio will result from this addition to its service.

Another result of the improvement in radio apparatus in the last few years is the introduction of a receiving device for determining the direction of the point from which radio signals are sent. This use of radio has value to marine practice second only to that of calling assistance in distress. A shore radio station equipped with this apparatus can, by properly adjusting it while signals are being received from a distant ship, determine with accuracy the bearing of the ship from the station. Then if two shore stations, rather widely separated, simultaneously determine the bearings of the ship from their respective stations, the intersection of these lines of bearing is the position of the ship. Usually the method followed is for one shore station to inform the other of its bearing determination, and the other then can combine this with its own determination, work out the ship's position, and inform the ship by radio telegraph. Also more than two shore stations will usually be used, in order to decrease the liability to error; as for instance around New York City harbor, four or five are used. Special direction finding stations are erected along the coast at important points, whose whole duty it is to determine the location of ships and inform them upon request. The accuracy with which positions can be given is ample for the purpose and fortunately increases with decrease of distance so that as vessels near the coast they can be located more and more accurately.

The process of finding the position of a ship might be reversed by equipping the ship with the direction finding apparatus and sending out radio signals from definite shore stations. This method is not as satisfactory as the first, mainly because it is not possible to obtain as great accuracy in direction finding on shipboard on account of the distortions introduced by the hull and rigging of the vessel itself. This application of radio is of great value to navigation, and there is high naval and marine authority for the statement that by it navigation will soon be made simple and safe. The importance of the direction finder to navigation can hardly be overestimated, and it will probably result in radical changes in navigational practice.

Another device of similar although more limited application possibilities is the so-called "pilot-cable." This is not strictly a radio device, but has been made possible by the use of certain instruments which were first used for radio purposes; namely, amplifiers for magnifying weak electric forces. The pilot cable is an insulated conductor laid along the bottom of a harbor entrance channel, through which alternating current is forced from a generator on shore. A weak magnetic field is then present around the cable and can be detected at a distance which depends upon the strength of the current and the sensitiveness of the detecting device on board the ship. Of course, the field is strongest near the cable. A detecting device, of either telephone receivers or some visible indicator, is placed on board the ship and connected to "pick-up" coils placed on both sides of the ship. The signal will be heard louder on the coil on that side of the ship which is nearer to the cable, and consequently if the ship is maneuvered until the signals from the two coils are equal in intensity, the ship will then be directly over the cable. Keeping in the channel is accomplished simply by maintaining equal intensity signals from the two coils. This device will have great value to harbor navigation during foggy weather when all other present channel indications fail. Probably, when the pilot cable comes into general use, with one cable for incoming ships and another for outgoing—the two having some characteristic difference to distinguish them—the present dangers and delays of harbor navigation during fog will be eliminated so that the pilot cable, together with the radio direction finder, soon will have removed the most serious present-day menaces to navigation.

After barely twenty years of service, we find that radio has extended communication to ships to every corner of the seas, will provide telephony as well as telegraphy, and can do much toward increasing the simplicity and certainty of navigation. The end is not yet, and we can reasonably hope for further new services from this young and versatile branch of electrical science.

Inter-communicating and Signalling for Merchant Vessels

By H. Franklin Harvey, Jr

Engineer, Electrical Division, Newport News Shipbuilding & Dry Dock Company

Since the days of the Ancient Mariner and the advent of the electrical age, means for communicating between different parts of a vessel have been greatly improved. The present day, however, still finds in use some of the early mechanical methods of transmitting signals. The captain nevertheless no longer depends upon the messenger for transmitting orders. His present methods are much faster and consequently more effective in efficiently handling the vessel and averting trouble or disaster.

Not only have most of the up-to-date merchant ships a radio connection with the mainland and other ships but in foggy weather they also have submarine wireless warning of sources of imminent danger and by means of the buried channel cables even have wireless guidance.

The gyro compass, too, has a foremost place in the handling of large merchant ships and is not subject to magnetic disturbances.

Electrical telegraphs are probably the most important of the ship's communication systems and among them the prevailing principle involves the step-by-step motor or the revolving magnetic pole motor. When the transmitter handle is turned the several contacts on it energize magnets in the receiving instrument and reproduce the signal from the transmitter. The number of poles for the motor is governed by the number of signals for the system, and the number of conductors required between the instruments is approximately the same as the number of signals to be given.

There are three divisions in the method of communication now used: (a) electrically-operated interior systems covering telephones, bell signals and calls, emergency alarms, fire alarms, rudder indicators, shaft-speed indicator systems, and telegraph systems; (b) electrically-operated exterior signals covering radio, Morse signal light, submarine signal, shore signalling lights, and ship's whistle

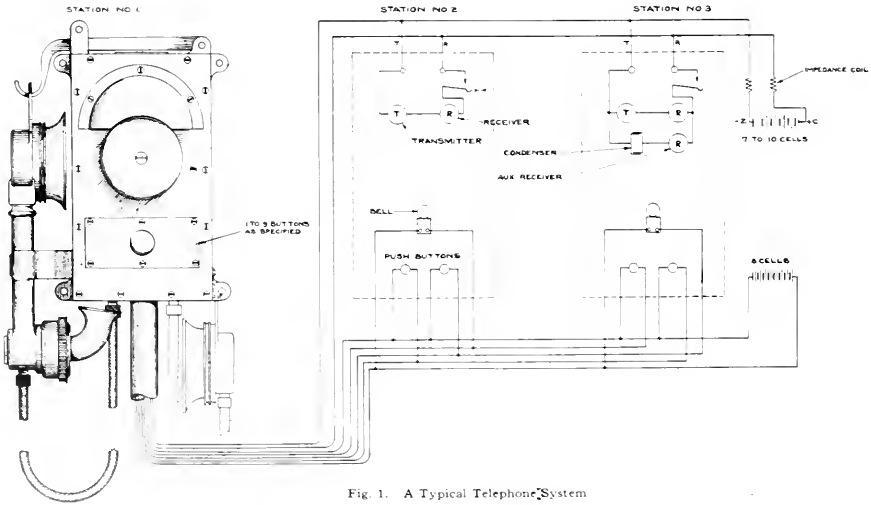


Fig. 1. A Typical Telephone System

operator; and (c) mechanically-operated systems covering voice tubes, engine order telegraphs, docking telegraphs, steering and rudder telegraphs, engine gongs and other bells, and ship's whistle pulls.

Electrical Interior Systems

The telephone system is chiefly employed for communicating between the pilot house, captain's stateroom, chief engineer's stateroom, engine room, and radio room. These telephones are provided with a calling system which enables any one of the stations to be called without disturbing the others. They are essentially very different from those used in land practice on account of their subjec-

emergency call system, the last being used only in event of collision or when other extreme danger threatens the ship. Bells or buzzers are installed at stations as required, such as pantry and steward, and they are operated by push buttons at locations from which those attendants are to be called. Annunciators are provided in order that the attendant may identify the station calling.

Bells or buzzers are also located at certain voice tube outlets and are connected to a push button at the other end of the tubes.

The emergency alarm signal is operated from the pilot house by means of a switch connected to bells located in passageways and quarters. This alarm is sounded only

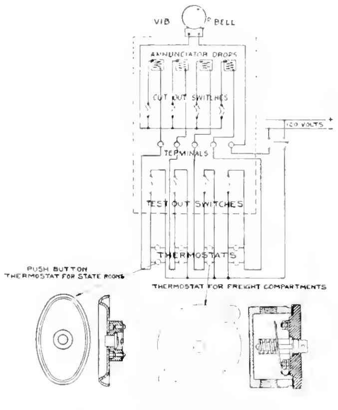


Fig. 2. Thermostats and Wiring Diagram for Fire Alarm System

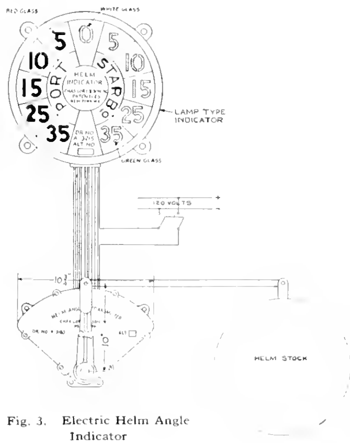


Fig. 3. Electric Helm Angle Indicator

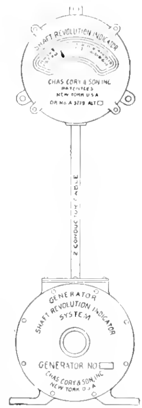


Fig. 4. Shaft Speed Indicator Outfit

tion to rough usage, changes in temperature, salt spray from the sea, moisture incident to sea travel, etc., all of which necessitate the most rugged and watertight construction, together with a highly efficient and sensitive design. The telephones are specially constructed to give service in the engine room and other locations where the noise of running machinery must be encountered. In these special locations they are usually fitted with an auxiliary receiver for excluding local noises and for aiding in receiving by employing the normally idle ear of the person using the telephone. Fig. 1 illustrates the general type of telephone.

Bell signal calls are used for telephones, voice tubes, special calls, and for the

in event of sudden danger in order that the personnel may be duly warned.

The fire alarm system, involving thermostats located in the freight and other compartments and connected to an indicator or annunciator in the pilot house or engine room, provides adequate fire detection in those spaces. The indicator gives both an audible and visible signal, the latter showing in which compartment the fire condition exists or threatens. The thermostats in common use are either of the fusible spring contact type or the mercury contact type. In the fusible spring contact type, when the temperature reaches the predetermined point at which the thermostat is set, the contacts are closed by the melting of the fuse which releases the spring, thus allowing the current to pass through the contact springs, completing the circuit to the annunciator and giving the alarm. See Fig. 2. In the mercury type the mercury column is connected at the bottom to the circuit, and when the temperature in a protected compartment rises sufficiently to cause the mercury to reach the upper contact, a current from a 6 to 12-volt battery passes through the column of mercury and completes the circuit. The predetermined temperature at which these thermostats are designed to close the circuit is usually from 150 to 190 deg. F. After the circuit is thus closed the alarm is automatically given at the annunciator in a similar manner to that for the other system.

The rudder indicator system shows at the steersman's stations, pilot house, and bridge, the position of the rudder in degrees. The contact maker is mounted on the helm stock and, as the rudder turns either way from the center line of the ship, contact is made with points corresponding to degrees deviation thus completing the circuit to the indicator and giving the angular deflection of the rudder. See Fig. 3.

The shaft-speed indicator shows at the engine room, as well as at the foregoing stations for the rudder indicator, the number of revolutions the propeller is making. To each shaft is geared a generator ranging from 2 to 60 volts. The generator is provided with a permanent field not affected to any extent by variation in temperature. When the shaft revolves a current is generated and energizes the voltmeter indicators which are calibrated in revolutions per minute. These indicators usually have a compensating resistance to provide for variation in the length of leads. The rudder indicator and shaft-speed indicator are not always used on merchant vessels. See Fig. 4.

While up to the present time mechanically-operated telegraphs have been used mostly, still many electrically-operated ones are in service and are giving very satisfactory results. These usually involve the combined transmitter and receiver type of apparatus. At one end of the line is an instrument with a handle which, when turned, makes contacts and completes a circuit to a magnetic pole in the receiver at the other end and attracts the pointer to the corresponding signal. This same operation is repeated at the receiving end when responding to the signal. See Fig. 5.

Electrical Exterior Signals

The submarine signal system is a device for locating the direction and approximate position of bell buoys along the coast and in shallow waters to give warning of approaching or crossing vessels. A receiving set, similar to the ordinary telephone type except with two receivers, one for port and the other for starb ard signals, is located in the pilot house or chart room. These are connected to diaphragms located port and starboard near the bow well below the water line and suspended in salt water tanks the outer sides of which are formed by the shell of the vessel. When a sound is detected in either receiver the ship is pointed alternately to port and starboard until the sound waves in both port and starboard receivers are of the same intensity thereby indicating that the vessel is heading toward the source.

The ship's whistle is operated electrically by means of current obtained from the ship's generators. Contact makers located at the bridge and pilot house complete circuits to magnets in the control mechanism and thereby manipulate the whistle valve and allow steam to enter for producing the blast. This whistle is provided with a switch which will automatically control the blasts or allow them to be controlled at will. The automatic feature is used for fog signals and in heavy weather as required by navigation laws. See Fig. 6. On ships without electrical control, the whistle is operated by hand pulls from the pilot house and upper deck.

For night signalling to nearby ships or to the shore the Morse signal light is employed and consists of a watertight lamp installed in an elevated position, generally on a pipe stanchion on the top of the pilot house. The Morse code is used and three signalling keys are ordinarily provided, one in the pilot house and one on each wing of the bridge. The lamp is usually fitted with a Fresnel lens for concentrating the light rays in the horizontal plane.

When loading tankers it has been found necessary to signal the shore end of the pipe line. For doing this, two red lights are installed on the mast about twelve feet apart vertically. These lights are operated in a pre-arranged manner for giving the proper signals. The ship's whistle, operated by contact makers in the pump room and at the filling pipes, is also used for this purpose.

Running-light telltale boards, located in the pilot house, provide a method of switching on or off the ship's electric running lights and show the failure of a lamp in any one of the

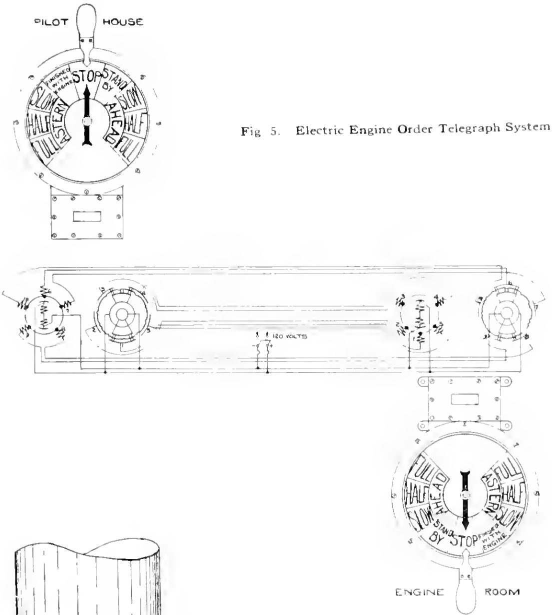


Fig 5. Electric Engine Order Telegraph System

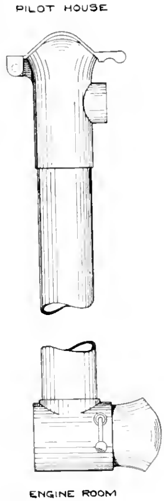


Fig. 7. Voice Tube Line

Fig. 8 Mechanical Engine Order Telegraph System

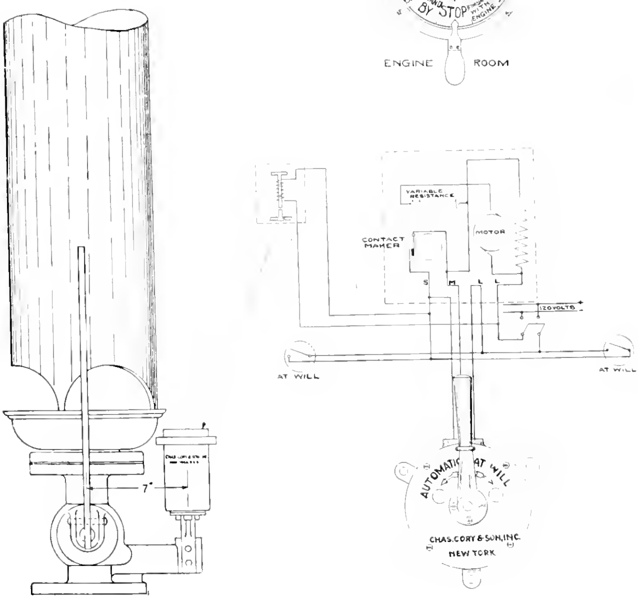


Fig. 6. Electric Operated Steam Whistle

various running lights by means of an indicating relay in each running light circuit. A buzzer signal also indicates the failure of a light and a second lamp in the light may be immediately switched on at the telltale board. This practice board prevents a running light from being in darkness any appreciable length of time and obviates the possible necessity of climbing the mast in the darkness to replace a lamp.

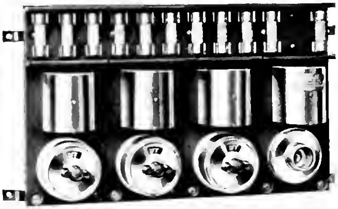


Fig. 9. Running Light Telltale Board Which Indicates Outage of a Running Light and Provides the Means of Cutting in the Spare Bulb When This is Desired Owing to Darkness, Heavy Seas, etc.

The latest type of telltale board is fused on all circuits and provides, in addition to its warning and switching facilities, a convenient distribution panel for the various running light circuits. The boards are now built in unit sections and can be readily extended to care for additional lights by the addition of relay panel units. See Fig. 9.

Mechanical

Instead of depending wholly upon telephones, voice tubes are also used for communication between the pilot house and the following stations: captain's room, engine room, radio room, crow's nest, to the check compass at the top of the pilot house, and such other stations with which direct communication is especially desired. These tubes range from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches in diameter and have mouthpieces at each end of the line for concentrating and properly directing the voice. Occasionally, there is a low-voltage bell at each mouthpiece operated by a push button at the opposite end of the tube and used for attracting attention. Ordinarily, however, these tubes have whistles inserted in the mouthpiece. These are blown by the party desiring to call at the other end and serve the same purpose as the call bell. See Fig. 7.

The mechanical engine telegraph provides a means of communicating orders from the bridge and pilot house to the engine room for directing the operation of the main propelling machinery. Transmitters are located at the bridge or pilot house and sometimes in multiple at both, and are equipped with dials on which the necessary orders are radially marked for governing the direction and speed of the ship. The instruments are fitted with a handle and pointer for transmitting the messages, and with an indicating arrow for receiving the reply from the engine room. A similar machine is fitted in the engine room. These stations are inter-connected by heavy brass wire leads for all straight runs and at all turns these leads are connected to brass chain leads around pulleys. The orders to the engine room are transmitted by moving the handle on the pilot house or bridge transmitter until its pointer is over the desired signal. This movement is transmitted over one pair of wire leads to the arrow on the engine room indicator. When turning the handle a bell signal is given at the indicator between each order for calling attention to the change in orders. The reply from the engine room indicator handle is made in a similar manner over another pair of wire leads. The adjustment of leads is made by locked turnbuckles and a uniform tension is provided by the use of compensators which allow for expansion and contraction and for the working of the hull in heavy sea. The latter requirement is an important factor incident to the larger ships and especially "tankers." See Fig. 8.

The docking and steering telegraphs are identical in principle with the engine telegraphs and differ only in the dial markings. The reply for the steering telegraph, however, is usually given by the actual response of the rudder and is controlled by a quadrant attached to the rudder head. This quadrant is properly connected for returning the position of the rudder in degrees to the transmitting stations.

The engine gong and jingle bell signals were, prior to the last two decades, used almost exclusively for transmitting engine orders from the bridge or pilot house to the engine room. They are still occasionally fitted as an auxiliary to the engine telegraph system, and on tug boats and river steamers are used in lieu of the telegraphs. Hand pulls are located at the bridge or pilot house or both, at the sides of the ship, and sometimes on the top deck at the stern. These pulls operate a large double hammer type gong, usually 18 inches in diameter with the starboard pulls connected to one hammer and the port pulls to the other. The jingle bell is located near the main gong and is used in conjunction with it for giving the complete signals. For a reply to the pilot house a hood is fitted over the gong and jingle and is connected by a brass tube to a sounder in the pilot house. The sound of the gong and jingle is thus conducted back to the sending station.

The ship's whistle, in addition to electrical operation as previously mentioned, is also operated by means of hand pulls located in the pilot house and on the bridge. These are connected to a lever which operates the steam valve on the whistle. The method of transmission is the same as for mechanical telegraphs, except that only one lead wire is used.

On large merchant liners several other electrical systems are used but in this article only the ones applying to the majority of the average size merchant vessels have been covered. There appears to be no limit to the application of electrical means for communicating signals and consequently the number of systems installed are governed by the cost involved and the desire of the ship owners.

Special Electric Instruments for Electric Driven Ships

By A. H. Mittag

Engineering Department, General Electric Company

In connection with the development of electric ship propulsion, there has arisen the need of some new electrical instruments. Two of these have been developed and are in use on the U. S. S. *New Mexico*, S. S. *Eclipse*, and S. S. *Cuba*. These instruments are known as the "excitation indicator" and the "field temperature indicator."

In Fig. 1 is shown the main operating board of the S. S. *Cuba*. The upper right-hand instrument is the alternator-field temperature indicator and the lower left-hand one is the excitation indicator.

Excitation Indicator.

The excitation indicator shows the operator when he has the correct value of alternator-field excitation, and when this excitation is not correct it indicates whether the excitation must be raised or lowered. It also indicates whether the motor and alternator are operating on the stable or unstable side of their combined characteristics, or in other words whether the motor is "in step" or "out of step" with the alternator. Strictly speaking an induction motor is never "in step" since it always runs at a slip, but the expression is here used to indicate that the motor is operating between synchronism and maximum or breakdown torque.

The correct excitation of the alternator field is the lowest excitation that will hold the motor in step. This is the most economical way to run and also gives the least amount of heating of the alternator field. It is of importance to keep the heating of the alternator field down to a minimum since this becomes hot before any other part of the alternator or motor.

The excitation indicator can be used regardless of whether the motor is an induction or synchronous machine. However in the case of synchronous-motor drive, the excitation of the motor field should be varied together with the alternator field so as not to change the line power-factor.

In Fig. 2 is shown a diagrammatic sketch of the excitation indicator and its connections to the lines between alternator and motor. As will be seen there are two elements in this instrument, one a current element and the other a potential element. The vanes of the

Fig. 1. Main Operating Board of Steamship *Cuba*

two elements are connected to a common movable shaft, and in such a way that when the stationary coils are excited, the torques produced in the vanes are opposite or bucking. Since there is no spring acting on the moving parts, the position taken by the shaft to which the pointer is attached depends only on the ratio of currents in the stationary coils of the two elements. The current element is connected directly to a current transformer in the line between alternator and motor. The potential element is connected in series with a high reactance x and then to a potential transformer as shown in Fig. 2. Thus the current in the potential coil is directly proportional to line voltage, and on account of the reactance x it is inversely proportional to the frequency of the line voltage. Therefore, the position of the pointer depends on line volts divided by line amperes and line frequency or

$$\frac{\text{Volts}}{\text{Amperes} \times \text{Frequency}}$$

If saturation in an alternator is neglected, then for any value of alternator-field excitation at a constant frequency and power-factor the ratio of line volts divided by line amperes is constant at the maximum of the kilowatt output curve. As a rule there is little or no saturation in an alternator when it is loaded up to maximum output with any value of field excitation that can be left on continuously, since due to the regulation the line voltage will be below normal. If the line current, power-factor, and excitation are kept constant, then the line voltage and kilowatts output will vary directly as the frequency. From this it follows that the fraction

$$\frac{\text{Volts}}{\text{Amperes} \times \text{Frequency}}$$

is constant when the alternator is loaded up to maximum kilowatts output at a given power-factor regardless of what the speed of the alternator or its field excitation may be, it being understood that the field excitation is not higher than can be left on continuously.

Therefore since the position of the pointer of the excitation indicator depends on the same fraction, this position is always the same when the alternator is operating at its maximum kilowatts output regardless of excitation or speed. If at a constant load the alternator is operating at its maximum output and if the field excitation is then increased, the line volts will increase and the line amperes will decrease causing the excitation indicator pointer to move in a certain direction; while if the field excitation is decreased, the line volts will decrease and line amperes will increase causing the excitation indicator pointer to move in the opposite direction. Thus the position of the pointer indicates whether the alternator is operating on the maximum of its output curve; whether it is on the stable side, that is, on the side where an increase in line current gives an increase in kilowatts; or whether it is on the unstable side of its output curve, that is, on the side where an increase in line current gives a decrease in kilowatts. This decrease in kilowatts output is due to the fact that the voltage decreases at a greater rate than the current increases.

In the case of electric ship propulsion equipments, the alternator can not hold the driving motor in step when operating on the unstable side of its output curve regardless of whether the motor is an induction or a synchronous motor, and if the motor is out of step it will pull the alternator over on the unstable side. Therefore when the pointer of the excitation indicator is in the region showing that the alternator is operating on the unstable part of its characteristic, the motor is out of step and should be brought into step; and when the pointer is in the region showing that the alternator is operating on the stable side of its characteristics, the motor is in step.

To run at the highest economy and with least heating of the alternator field, the alternator-field excitation should be kept as low as will hold the motor in step; in other words, the alternator should operate as near the maximum of its output characteristic as the variations in propeller load will allow.

This instrument cannot be taken from one electric drive equipment and be connected to another equipment of different design without changes and recalibration.

necessary on the field of the synchronous motor.

A diagrammatic sketch of this instrument with connections to the alternator-field circuit is shown in Fig. 3, where it will be seen it is similar to the excitation indicator. It consists of two elements, a potential and a current element. The vanes are attached to a common movable shaft at such an angle with respect to each other that, when the two stationary coils are excited, the torques produced in the vanes are in opposite directions or bucking. There is no spring acting on the movable shaft. The resultant position taken by the shaft, to which a pointer is attached, depends only on the ratio of currents in the two stationary coils; or since one coil is connected across the field and the other in series with the field, it depends on the ratio of volts applied to the field to the current in the field, or in other words, the field resistance.

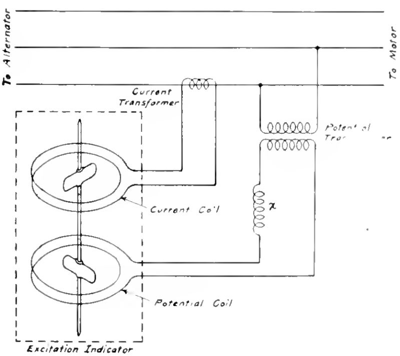


Fig. 2. Diagram of Excitation Indicator

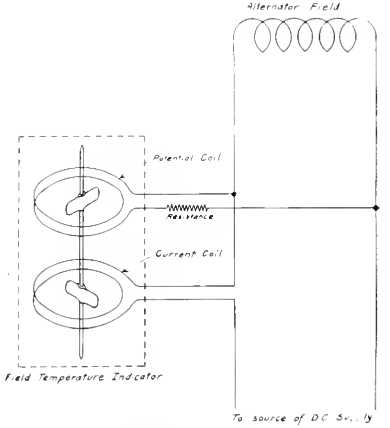


Fig. 3. Alternating-current Generator Field Temperature Indicator

Field-temperature Indicator.

The field-temperature indicator is an instrument that shows the temperature of the field conductor and depends for its operation on the change in resistance of a conductor with change in its temperature. It really indicates electrical resistance, but instead of a scale of resistance a scale of temperature in degrees Fahrenheit is used.

This instrument is employed on the alternator field only, no such instrument being

Then since there is a definite relation between the resistance of a copper conductor and its temperature, the instrument is calibrated directly for temperature.

The instrument has to be calibrated for the field to which it is to be connected and cannot be used on another alternator without recalibration, since the field resistance of another alternator may be entirely different at the same temperature.

Ship Lighting

By R. W. Peden
Edison Lamp Works, General Electric Company

Introductory

Ship lighting is an interesting and broad subject, for the modern passenger vessel is virtually a small town with diversified lighting demands just as found on shore. The problem is further complicated by the fact that there is a minimum of space available for hanging fixtures. There are no walls in which to conceal the wiring and, in the majority of cases, it is impossible to take advantage of many of the methods of installation which are used on land and which add much to the appearance of the system in general.

It is interesting to note that the steamship *Columbia*, built in 1879, was sent to New York City in 1880 to be fitted with the first Edison incandescent lighting plant that was ever installed for commercial use. The original methods of application were indeed crude compared with present-day standards.

Ship lighting has since advanced by rapid strides, but the decorative features have progressed faster than the utility developments. This is parallel with other experience. Industrial lighting, for example, has been long neglected, glaring and inefficient sources being employed. The day is not far distant, however, when those having authority over ships will realize the advantages of modern lighting equipment. The lighting of the working parts of the ship offer the greatest opportunity for improvements.

Special Requirements of Wiring

Escape from a ship at sea is always acc mpanied by considerable danger and therefore it is most essential that the fire hazard be reduced to a minimum by employing only high-grade wiring systems and suitable fittings.

In passenger vessels, especially, precautions should be taken to include duplicate generating equipment. Both turbine generators and vertical reciprocating engines are used as prime movers. The capacity of generators ranges from one kilowatt on small vessels to 400 kilowatts on large ocean liners.

The advantages of strength and reliability of 110-volt lamps have been generally recognized and three-wire 220-volt, or two-wire 110-volt distributing systems are employed. In the best installations, the power and lighting circuits are separate.

The protection of feeders is one of the most important considerations in the wiring of a vessel. Preservation of the life of the traveling public and continuity of service both depend upon it.

Special Requirements of Fixtures

The electric fittings used on board ship must be of strong, substantial design and sufficiently rigid to withstand the motion of the vessel. In general, the low head room makes it necessary that they be short. There are three general classes of fixtures to be found on the modern vessel: (1) special ornamental or decorative fittings for the salon, music hall, smoking room, first-class dining room and the like (these are of the same general type as used on land); (2) utility type fixtures, such as are employed in the general state rooms, passageways, and similar parts of the boat (these correspond to the commercial type of fixtures used where especial attention is not paid to artistic results); (3) water-tight fittings such as are necessary in the engine-room, on the open deck and other parts of the vessel exposed to the elements.

The essential parts of a water-tight fixture are a cast-iron or steel fitting into which a glass enclosing globe may be screwed and a rubber gasket placed between the metal and glass. The metal fitting is attached to the conduit or may be fastened to a water-tight pull box. Most water-tight fittings are so constructed as to make possible the attachment of a wire guard for protection of the globe from mechanical injury. Clear Mazda lamps are usually employed, although in many instances frosted or enameled lamps are desirable on account of the added diffusion. Reflectors are rarely used, although they can be satisfactorily accommodated to this type of fitting and their use would prove of value in many cases.

LIGHTING PRACTICE AND REQUIREMENTS

Salons

The decorative element of lighting is predominant in salons. If space permits, massive ornamental ornate fixtures are employed; often of special design as indicated in Fig. 1. No set rules can be laid down for the lighting as the keynote of an artistic installation is originality, but whatever system is

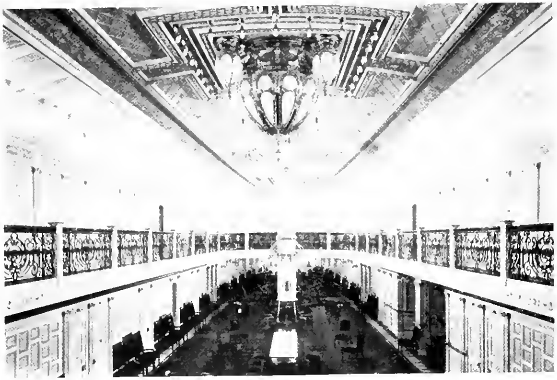


Fig 1. View of a Social Hall on a Coastwise Vessel Illustrating the Massive Ornamental Fixtures Often Justly Employed for Public Spaces on Shipboard

Fig 2. Social Hall of a Coastwise Steamer with Low Ceiling Height. Diffusing ceiling hemispheres are employed with clear bulb lamps

Fig. 3. The Library on an Ocean Liner Illuminated by a Combination Consisting of a Decorative Type Close Ceiling Fixture and Silk Shaded Wall Sconces. The coloring of the shades gives a touch of life and warmth to the interior. Desk lamps supplement the general illumination employed to provide a high intensity over the "working" area

Fig 4. The Dining Room on an Ocean Liner Illuminated to a Low Intensity by Close Ceiling Type Units, the General Lighting Being Supplemented by Silk Shaded Table Lamps Supplied from Baseboard and Floor Outlets. This combination proves very effective in promoting an attractive dining salon

employed it should serve to make the room comfortable. Bright light sources particularly against dark backgrounds are glaring and annoying. An average intensity in the neighborhood of two or three foot-candles is adequate for the purposes for which these portions of the ship are used.

Where the ceilings are low as indicated in Fig. 2, it is necessary to employ a number of smaller units to get a suitable distribution of light.

Writing Room or Library

The warm, cozy effect necessary when illuminating a room of this character is obtained by the use of a low intensity of general illumination from some form of decorative overhead fixture supplemented by candlestick brackets or sconces. Suitably shaded decorative reading lamps on the writing desks give another touch to the installation. A library on a large liner where this general scheme of illumination is followed is pictured in Fig. 3.

Dining Room

The dining room of the modern ocean liner offers conditions quite similar to those of the first-class hotel grill room with its low ceiling. Two practices exist as to lighting: the provision of a sufficient intensity of general illumination by means of small rather closely spaced overhead units, or the use of a low intensity of general illumination supplemented by local or table lamps throughout the room. The second practice is pictured in Fig. 4. As would be expected, the lighting in the second and third-class dining rooms is considerably less ornate and the fixtures are of a more utilitarian character.

Smoking Room

The decorative requirements and the necessity for comfortable lighting are common in this room as well and individuality of treatment is desirable. A moderate intensity of general illumination, approximately three foot-candles, is desirable in order that card games may be indulged in without eye strain.

State Room

The state room is essentially the bed room of two or more persons. It must at the same time be the lady's boudoir, the gentleman's dressing room, and not uncommonly it is called upon to take the place of the hospital ward. Thus, there are four distinct rooms in one which seldom occupies a space greater than 8 by 8 by 7 feet. Despite the minimum space available, the traveling public wants the same conveniences on shipboard as are found on land under similar conditions, that is, the bed room must have good general illumination supplemented by reading lamps at the heads of the beds. The boudoir must be so lighted as to produce a warm and cozy effect, at the same time supplying ample illumination on the dressing table. The men's dressing room requires good illumination at the mirror for shaving; while the hospital ward calls for a subdued light which will add to the comfort of the patients and yet permit the nurse or attendant to move about with facility.

It is obviously impossible to meet all these requirements in the most effective manner in the space available and as a result, in many instances, very little consideration has been given to the lighting of the state room. The view shown in Fig. 5 is fairly typical of the average installation. A single unit consisting of a very simple type of ceiling receptacle with a round bulb all-frosted Mazda lamp is placed in the center of the open space. At the side of the berth will be noticed a portable auxiliary unit.

In some of the more recent installations, the first-class state rooms of modern ocean liners have very elaborate systems of lighting. Such installations are very satisfactory and illustrate what an important adjunct proper lighting is for comfort and convenience.

Working Areas

The United States Navy has conducted scientific research along the lines of the physiological effect of proper and adequate lighting on the crew and on the consequent handling of the ship in general.

It has been shown that good illumination creates cheerful surroundings, inspires endeavor, and results in better performance. In addition to preventing accidents that are caused by inability to see clearly, it enables the crew to move about their work quickly, easily, and with confidence. These factors make possible the proper and rapid loading of the vessel, thus economizing time at the dock and preventing the shifting of cargo when at sea.

Engine and Fire-room

It is very difficult to illuminate properly such spaces as the engine and fire-room on account of the multitude of overhead pipes, beams, and deck supports. The surroundings, too, are often of a dark color.

It is often necessary to make repairs when at sea or under other circumstances where time is a valuable asset and since a very high intensity of light is thus temporarily rendered

Fig. 5. A Typical Stateroom Lighting Installation. One central ceiling fixture employing a round bulb all-frosted Mazda B lamp and an adjustable reading lamp by the side of the berth. Enclosing glassware or fabric shades would have remarkably improved the installation

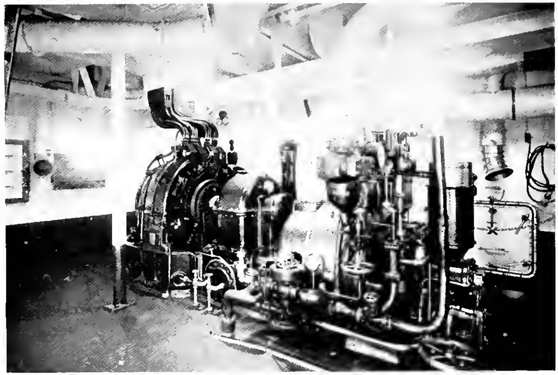


Fig. 6. The Dynamo Room on One of the United States Battleships. It is interesting to note the excellent diffusion produced by the white walls, ceiling and piping. Contrary to what might be termed "standard practice" reflectors are employed in addition to the vapor proof enclosing globe

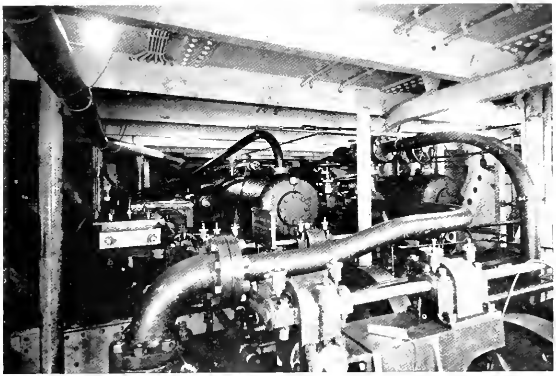


Fig. 7. An Auxiliary Engine Room with Lighting Better Than the Average. An opalescent globe diffuses the light, while a porcelain enamel reflector on one of the important units produces a relatively high utilization

Fig. 8. Localized General Illumination Over a Ship's Galley. Outlets at regular intervals over the benches or tables give the maximum light where most needed and yet provide sufficient spread for the aisles and passageways

essential numerous outlets for auxiliary units must be provided.

In modern installations, the type of fixtures are materially the same as those employed on land under similar conditions, but the addition of suitable reflectors and diffusing mediums adds materially to the utility and appearance of the entire system. Figs. 6 and 7 are typical modern installations for engine-room, fire-room, auxiliary engine spaces, etc. A comparison of the two illustrations reveals the advantage of a white finish for interiors.

Galleys

In the galley, light is essential for three purposes: First, to enable the cooks and other attendants to prepare the meals with sanitation and ease; second, to supply a light of sufficient intensity to impart confidence to the stewards as they move around with loaded trays; and, third, to insure the rapid loading and handling of supplies.

Since the benches, tables, and cooking ranges serve as the boundaries of the various passages, good results may be obtained by installing a sufficient number of units over the former. Fig. 8 shows an installation of this nature. Since the ceiling is usually a pure white, reflectors are not as essential here as in many other areas. Glaring clear lamps and clear globes should always be avoided, and the units should be placed close to the ceiling rather than hung low, because glare and accidental breakage is thus diminished.

Freight Decks

From the point of view of the illuminating engineer, the freight decks are practically an untapped field. The majority of modern ships have no permanent artificial light in the freight spaces because there is no fixture on the market today which is rugged enough to withstand the service to which it is here subjected during loading and unloading; also, construction of these spaces and the use made of them renders it difficult to so conceal the wiring as to adequately guard it against injury.

Portable units are now in use in these spaces. These are of the multi-lamp type and employ porcelain enamel reflectors. Some installations provide vapor-proof portable receptacles on each deck at the hatchway, but this is an unsatisfactory arrangement as the portable units are in the way and the conduits are often wrenched from their fastenings.

Speaking of the working areas in general, the [illegible] of good illumination cannot be attributed to economic causes. Most landsmen are forced to buy power from an independent company but ship operators generate current for their own use and consequently pay a minimum price. Hence, from a supply point of view, the ship owner has the advantage of his brother on land yet has been slow to profit by the result of recent experiments.

The remedying of this condition is a problem which can be solved only by extensive experiment and close co-operation between fixture manufacturing companies, shipping concerns, and insurance authorities. There can be no doubt that infinitely better systems than those in use could be found.

Passageways and Decks

On the modern ocean liner, passageways are so constructed as to allow two persons to pass each other, yet each passage may serve as the gateway for a hundred or more state rooms. These passages are generally located between two rows of state rooms, hence very little daylight can penetrate to them and artificial light must be used continuously. A good general illumination meets the requirements at all times, but it is advisable to have some device for increasing the night intensity over that used in the daytime. Here, as in other parts of the boat, flat white finish of surroundings reduces glare and gives better diffusion.

The illumination on the open decks should be sufficient to reveal obstacles, but a high intensity is not desirable, for the public prefers to take full advantage of moonlight scenes on the water and this is impossible when the local illumination is intense. The lighting arrangements vary but little, vapor-proof fixtures being placed overhead at distances from 15 to 20 feet. Clear outer globes are most common with clear Madza lamps as the source of light.

Conclusion

The foregoing article has been confined to the more important phases of ship lighting. It is obviously impossible to take up such a broad subject in detail in a limited space. The general practice has been pointed out but the best results can be obtained only by thorough familiarity with the actual conditions under which an installation is to operate. This can best be accomplished by whole-hearted co-operation between the shipping companies themselves and the manufacturers of electric lighting equipment.

Merchant Marine Searchlights

By G. E. Young

Searchlight Department, General Electric Company

There is an increasing realization among ship builders, ship owners, and mariners that the searchlight is an essential part of a ship's equipment and that the operation of a ship without a searchlight amounts to taking an unnecessary risk, not only in regard to the ship and her cargo but in regard to the lives of passengers and crew. This is evident when we consider its uses in connection with the following:

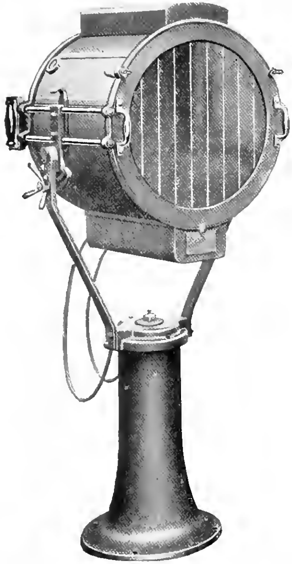
1. Locating man overboard.
2. Assisting another ship in distress.
3. Passing through wreckage.
4. Signalling between ships or between ship and shore when the searchlight is equipped with a signalling shutter.
5. Lighting buoys and other navigational marks.
6. Lighting docks in landing or during coaling operations.

Modern searchlights are equipped with automatic-feed horizontal-carbon type lamps and require very little attention during operation. Four types of control have been developed, each finding its application under various installation conditions.

The hand-control type is operated in both horizontal and vertical planes by the use of handles attached to the searchlight barrel as shown in Fig. 1.

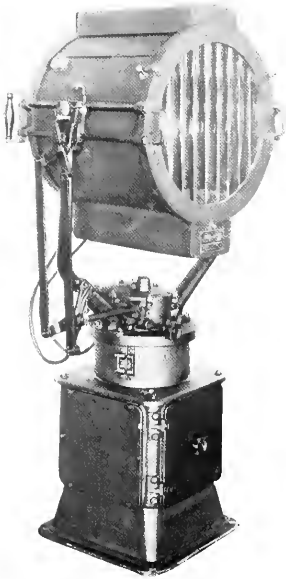
The pilot-house control type is mounted on the roof of the pilot house and is controlled from inside the pilot house by a single lever as shown in Fig. 2.

The rope-control type is a modification of the pilot-house control type and is controlled by a single lever which, instead of being directly attached to the searchlight, is connected to it by bronze tiller ropes which pass over sheaves and thus allow the control



Hand control

Pilot-house control



Electric remote control

Figs. 1, 2, and 3. Types of Searchlights for Merchant Marine Service handle to be mounted in a position which is not necessarily in direct line with the searchlight.

The electric control type permits the mounting of the searchlight in any position, sometimes on a platform well above the deck, and the control of it from one or more stations in any part of the ship. Connection is made between the searchlight and the electric controller by a multi-conductor cable, and a transfer switch may be installed to throw the control from one station to another. It is often convenient to have a control station at each end of the bridge. Fig. 3 illustrates a searchlight of the type described.

A distant electric control has recently been developed in which only one motor is used, the movements up and down and right and left being obtained by magnetic reversing clutches operated by the distant electric controller.

The Electrically Propelled Cargo Boat *Eclipse* and Passenger Ship *Cuba*

By E. C. Sanders

General Electric Review

One of the outstanding engineering achievements of the past decade is the successful development of means whereby the economical high-speed turbine is made applicable to ship propulsion. During this period, turbine-electric drive of large naval vessels and turbine-gear drive of merchant ships have demonstrated their superiority over reciprocating-engine and low-speed direct-connected turbine drive for these types of craft. It is quite fitting, therefore, that the closing months of 1920 should give birth to a further innovation, the turbine electric drive of merchant ships.

Future development along this line of application will be greatly facilitated by the fact that the two initial installations will afford an exceptional opportunity to study simultaneously the performance of electric equipment of different character in different service; induction-motor drive in the cargo boat *Eclipse* and synchronous-motor drive in the express passenger boat *Cuba*.[1]

Fortunately, for the sake of further comparison, electrification on the *Cuba* has been extended to include the deck and engine-room auxiliaries, while steam operation has been retained for the corresponding equipment on the *Eclipse*.[2] This divergence can but result in verifying the economy of electric drive for the secondary equipment of a ship.

[1] In connection with these installations, it is of interest to note that the electric propulsion machinery replaced turbine-gear drive in the *Eclipse* and reciprocating-engine drive in the *Cuba*.

[2] In explanation it should be stated that, at the time of rehabilitating the two ships, the steam auxiliaries on the *Eclipse* were in sufficiently good mechanical condition as not to require replacement.

[3] A description of the Scotch Marine Boiler and the Dahl oil burner will be found in the article by W. F. Carnes in this issue.

[4] The locomotive type of superheater is described in the article by H. B. Oatley in this issue.

Equipment of the *Eclipse*

The *Eclipse* is the first of twelve vessels of the United States Shipping Board to be equipped with electric propulsion machinery. She is 440 feet long, 56 feet beam, and of 11,868 dead weight tons.

The boiler room contains three Scotch marine boilers each equipped with three Dahl oil burners.[3] In conjunction with superheaters of the locomotive type,[4] they are designed to deliver steam at 215 lb. gauge pressure and 200 degrees superheat.

The propulsion machinery fundamentally consists of a turbine direct connected to an alternating-current generator which supplies power to an induction motor that is direct connected to the propeller shaft.

The turbine is of the Curtis impulse type, has eight stages, operates condensing, and normally runs at 3000 r.p.m. The generator is three-phase and rated at 3380 kv-a., 50 cycles, 2300 volts, 3000 r.p.m.; the motor is rated at 3000 h.p., 2300 volts, 100 r.p.m., and the rotor is phase wound.

The speed of the turbine can be varied over a range from 20 to 110 per cent normal by changing the setting of a speed lever which is located on the control board and connected to the variable speed hydraulic governor on the turbine. Double protection against overspeeding is afforded by the use of a pre-emergency governor of the centrifugal type which operates at 110 to 115 per cent normal speed, and a ring-type emergency governor which trips the emergency clapper valve and shuts off the steam supply to the turbine in case the speed should rise to 125 per cent. A throttle valve located below the hydraulic governor controlled valve permits the steam supply to be regulated by hand.

Excitation current for the generator is derived from two 35-kw., 125-volt direct-current steam-engine-driven generators which also supply current to the master controller and to the motor-driven blower for ventilating the induction motor.

Determination of the proper excitation current is simplified by two instruments, one of which indicates the maximum that can be applied without overheating the generator field and the other which indicates the minimum necessary to hold the induction motor in step with the generator.[5]

The starting, stopping and reversing of the ship are accomplished by means of a switchboard panel, contactors, and water-cooled resistor which control the operation of the induction motor in conjunction with the turbine-generator.[6]

The performance of this initial installation of electric drive on a cargo boat is gratifying. On November 9, 1920, the *Eclipse* sailed from New York for the Dutch East Indies and, after crossing the Atlantic in two days less than the regular schedule time, reported that all the equipment was operating satisfactorily and that the captain found great improvement in handling the ship in storm and in maneuvering in port.

Equipment of the *Cuba*

The *Cuba* is 320 feet long, 40 feet beam, and has a displacement of 3580 tons.

Her boiler room contains four Scotch marine boilers each equipped with three furnaces of the Morrison type fitted with White oil burners. The steam generated at 190 lb. gauge pressure is superheated 200 degrees by locomotive type superheaters. Preheated air is supplied to the boilers from the ventilating system of the propulsion generator and motor.

The principal difference between the propulsion machinery of this vessel and that of the *Eclipse* lies in the use of a synchronous motor instead of an induction motor for driving the propeller, with corresponding differences in the control equipment.

[5] The temperature indicator and excitation indicator are described in the article by A. H. Mittag in this issue.

[6] A complete description of the control of the propulsion machinery is given in the article by R. Stearns in this issue.

[7] The spring thrust bearing for marine application is described in the article by T. W. Gordon in this issue.

The turbine-generator unit is composed of an eight-stage Curtis turbine direct connected to a three-phase, 2350-kw., 50-cycle, 1150-volt, 3000-r.p.m. generator. The motor has a capacity of 3000 h.p at 1150 volts, 100 r.p.m. Made integral with the forward bearing housing of the motor is a spring-thrust bearing which supersedes the inefficient horse-shoe type bearing long used to absorb propeller thrust.[7]

Two geared-turbine three-wire generator sets supply direct current at 115 and 230 volts for excitation and lighting. A two-stage, 50-kw., 125-volt, turbine-generator set is installed for lighting when the ship is in port and the exciters are shut down. The speed of the main turbine is controlled by the same system as is used on the *Eclipse* and the safeguarding against overspeeding is accomplished in like manner. The field temperature indicator and excitation indicator referred to in connection with the *Eclipse* are also included in the equipment of the *Cuba*.

The control equipment enables the engineer to maneuver by simply operating two levers, an electric lever for starting and reversing and a speed lever for controlling the turbine. The electric lever is attached to a master controller which automatically opens or closes contactors in the proper sequence so that in starting the motor operates as an induction motor and, when up to speed, operates as a synchronous motor. Another feature wherein the operation of this equipment differs from that of the induction-motor driven *Eclipse* is that, in stopping, the synchronous motor automatically operates as a generator, returning power to the turbine-generator. If conditions necessitate, the control can be effected manually by means of reverse and field levers which operate the contactors directly through cam shafts.

On the official trial trip of this boat the propeller was brought from full speed ahead to a dead stop in two and one-half seconds and to full speed astern in seven and one-half seconds additional. The rapidity of this reversal brought the speed of the vessel from full speed to a dead stop in 140 seconds, which is considered remarkable in view of the fact that from four to ten minutes are required to stop the corresponding reciprocating engine-driven ship.

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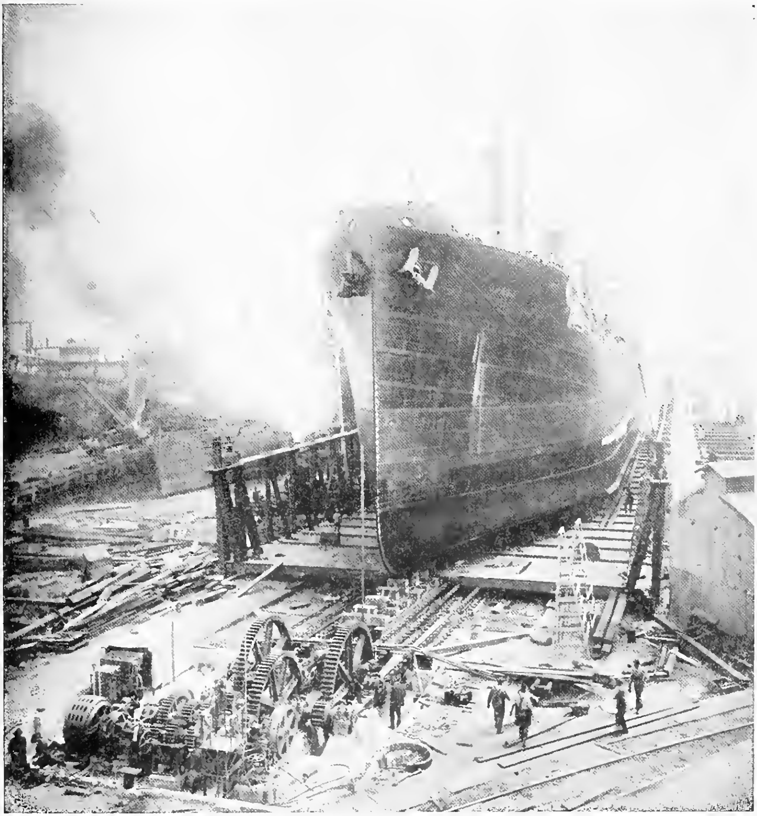

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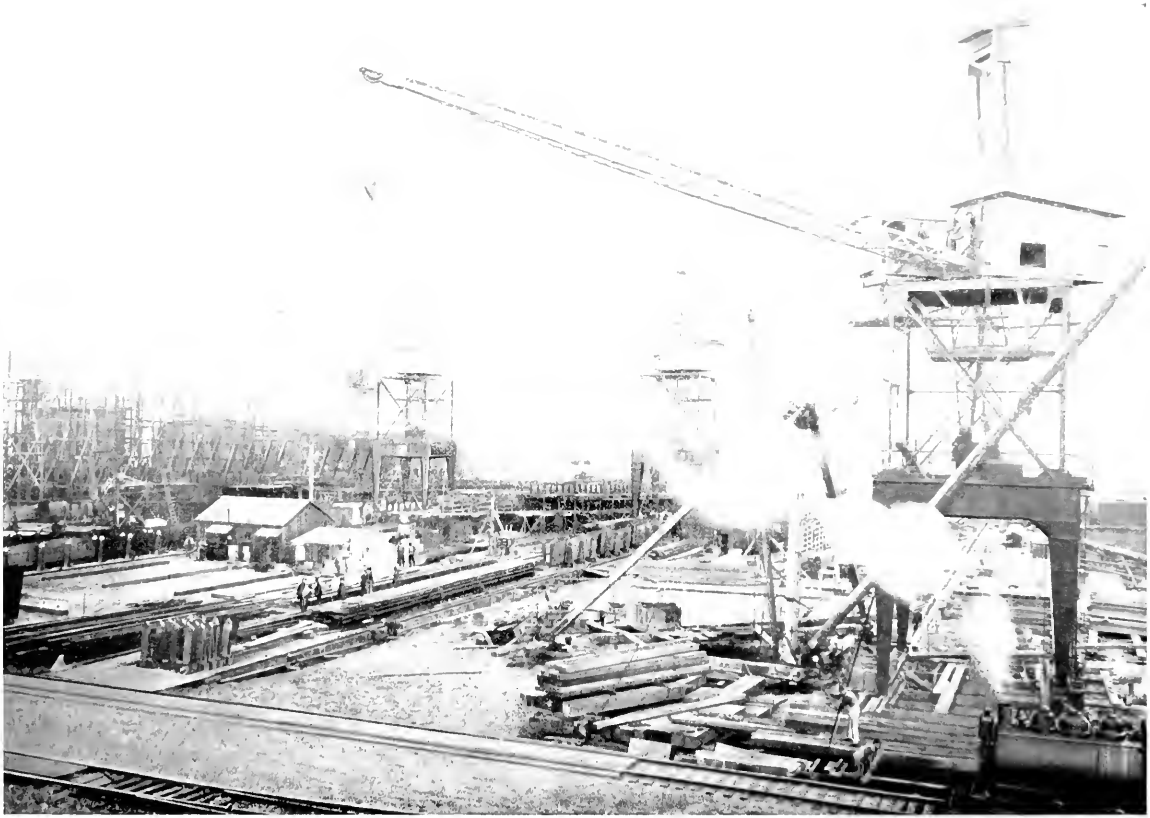


Five Four-motor Traveling-jib Cranes in the Shipyard of the Union Construction Company, Oakland, Calif. Each crane is capable of lifting 5200 lb. at a speed of 150 ft. per min. at a radius of 76 ft. or 15,600 lb. at a speed of 50 ft. per min. at a radius of 35 ft.

GENERAL ELECTRIC REVIEW

HONORS FOR DR. WILLIS R. WHITNEY

In recognition of his services to science and industry through applied chemistry, Dr Willis R. Whitney was awarded the Perkin medal on January 14th. He was the unanimous choice of the Committee on Award, and this choice, we feel confident, has the unanimous approval of the chemical fraternity.

Full credit for the organization, development and accomplishments of the celebrated Research Laboratory of the General Electric Company has been accorded time and again to Dr. Whitney, its director, no less by his assistants than by the great body of scientists everywhere, despite his protestations and characteristically generous endeavor to reflect the glory to members of his staff.

An impression of the esteem with which Dr. Whitney is regarded by distinguished men outside his own company is imparted by the addresses made at the time of the presentation of the Perkin medal. Dr. Arthur D. Little, in the course of reminiscences of Dr. Whitney's early work and personal characteristics, said:

"Someone has said that an institution is the elongated shadow of a man. Never was this more true than in the case of the General Electric Laboratory. Its achievements are the work of many men to whom they have brought deserved distinction. None the less, the laboratory as the entity and organization which has made this achievement possible is a projection of the personality of Willis R. Whitney, and in this sense its achievements are his achievements.

"He can recognize genius and he is big enough to allow the man of genius to develop at his side. He has no wish and makes no effort to dominate. He scrupulously apportions credit where it belongs. Jealousy is alien to his nature. These are the characteristics of the ideal director of research * * * * *.

"Willis R. Whitney is a great scientist, but he is not the scientist of fiction or of the stage. He is an intensely human individual. He is extremely fond of outdoor life and it keeps him sane and wholesome. He is a farmer, not a gentleman farmer but a dirt farmer, who knows hog cholera and manure and what to do when his hens have the pip. He raises flies and kills them with X-rays to cure their cancer. Some day he may kill the cancer first. * * * * But do not let me convey the impression that Whitney approaches these vocational interests in the spirit of the dilettante. His knowledge of them is not broad and thin, it is both broad and deep.

"In a very striking way and more nearly, as it seems to me, than any of his contemporaries, Whitney has the mental attitude and scientific breadth of an earlier generation in the scientific world, the ability to correlate and integrate observations and deductions in wide and different fields.

"The Perkin medal is the badge of knighthood in American chemistry. It has never been more worthily bestowed. Its latest recipient has inspired numberless young men; he has brought distinction to a great corporation and proved to financiers that research pays; he has brought new luster to American chemistry. The spirit of research has laid her hands upon him, and the spirit of youth as well."

The first impression of the Perkin gold medal was presented to Sir William Perkin in October, 1906, in celebration of the fiftieth anniversary of Sir William's discovery of the dyestuff mauve. This medal has been awarded annually since 1906 to the American chemist who has most distinguished himself by his service to applied chemistry.

The Willard Gibbs medal, founded in 1901 by William A Converse of the American Chemical Society, is bestowed annually for conspicuous achievement in and encouragement of eminent research in theoretical or applied chemistry, and was awarded to Dr. Whitney in 1916.

Dr. Whitney was also presented with the Chandler medal in 1920 for his accomplishments in science. The recipient of this medal is under obligation to deliver a lecture, and the subject of Dr. Whitney's paper was "The Littlest Things in Chemistry."

The Selsyn System of Position Indication

By E. M. Hewlett

Engineer, Switchboard Department, General Electric Company

By means of the Selsyn system, reliable and accurate indications of the position of a moving device are instantly communicated to a remote observation point. Fundamentally, the system consists of a special electric transmitting generator electrically connected to a similar receiving motor. After explaining the principle of operation the author of the following article describes the extensive installation of this system made at the locks of the Panama Canal and the similar equipment that will be placed in operation at the locks of the New Orleans Industrial Canal. Various other useful applications, such as to floating dry docks, Bascule bridges and signaling between control room and engine room, are also described—Editor.

The Selsyn system of position indication depends for its operation on a Selsyn generator and a Selsyn motor so constructed and interconnected, as shown in Fig. 1, that every angular movement of the generator rotor is duplicated instantly by a similar movement of the rotor of the motor.

The generator rotor is operated by mechanical power; the motor rotor is operated electrically. Thus both machines can be located at practically any distance apart and where most desirable.

The stator windings are interconnected at three equidistant points as shown. The rotor slip rings are connected in multiple and fed by low potential power.

Signaling

For transmitting predetermined signals or instructions the shaft of the generator rotor is attached to a handle and pointer which moves over a circular dial on the outer edge of which are printed the signals or instructions to be given.

The shaft of the Selsyn motor is fitted with a pointer which moves over a similar dial. Thus when the transmitter pointer is turned to any point the indicator pointer moves in unison to a similar point on its dial and gives the instruction or the signal desired.

For answering signals or instructions a duplicate set of position indicators are used, arranged in the reverse order.

Position Indication

To indicate visually the position of a water gate, float, valve, bridge gate or other device that has a restricted motion, horizontal, vertical, angular or these in combination, the Selsyn system can be used to marked advantage. In such cases the rotor of the generator is connected mechanically by means of gears, belts or otherwise to the movable device in such manner that a movement of the device causes a movement of the rotor. Since the Selsyn motor will duplicate the movement of the generator rotor it can indicate the speed [illegible] the device where desired by means of a pointer or other suitable arrangement—such as a miniature of the device itself—attached to the rotor shaft of the Selsyn motor.

The Selsyn System for Switchboard and Generator Room Signaling

An early application of this system (Fig. 2) was at the Keokuk Plant of the Mississippi River Power Company to send and receive signals between the switchboard and the generator rooms, neither of which is visible from the other.

Pedestals at the switchboard carry both transmitting and receiving equipment. Further provision is made for call bells in both directions and also lamp illumination for quick location of the unit at which attention is required. The sending equipment consists of a Selsyn generator, the shaft of which is brought out through the face of the pedestal and provided with a handle-crank for rotation. A dial marked at intervals with STOP, START, and other suitable designations back of the handle gives the operator the means for transmitting signals.

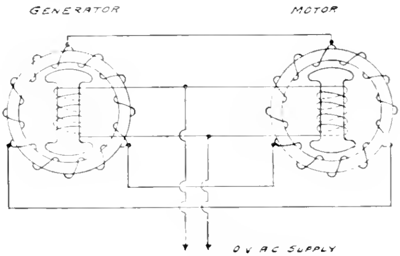


Fig. 1 Typical Connection Diagram of Transmitting and Indicating Units of Selsyn System

The Selsyn motor is located at the back of an indicator dial bearing the same signals similarly placed as those on the sending dial, but located on the switchboard (Fig. 2), or on another pedestal at the switchboard panel for the particular unit to be controlled. At the switchboard there is installed a sending equipment similar to that at the generator, which is connected to the Selsyn indicating motor on the generator pedestal.

The method of signaling is as follows:

When the switchboard operator desires to send a signal he turns the handle to the proper place on the dail. This revolves the Selsyn generator behind the dial and causes the Selsyn motor and the pointer on the indicator in the generator pedestal to take the same position. He then pushes a button to the right of the handle. This lights a lamp on the generator pedestal and rings a bell to attract the attention of the man in charge of the machine. As soon as the attendant has read the signal on his indicator he will turn the handle of his transmitter on the pedestal to the same signal. He will then push the button at the right of the handle, which will extinguish the lamp and stop the bell. Next he will push the button at the left of the handle, which operation will light a lamp and ring a bell at the switchboard. This advises the switchboard man that his signal has been received and correctly interpreted. The witchboard operator will then push the button at the left of his handle which will put out the light at his station and stop the call bell. Both operators may then move their respective handles to the "off" position. This completes the cycle of signal operation.

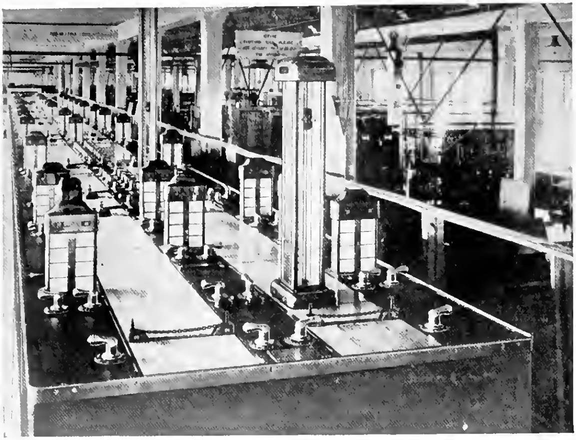


Fig. 3. Lock Control Board of the Panama Canal

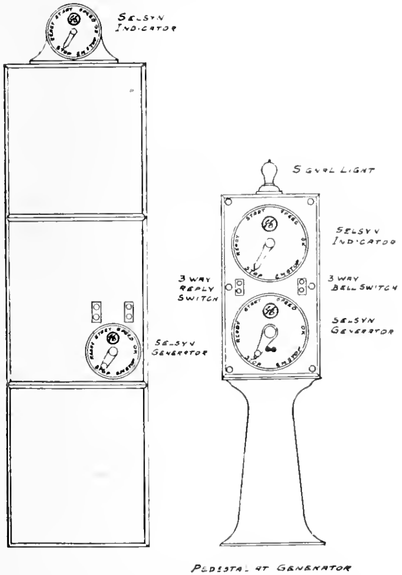


Fig. 2. Selsyn Position Indicator Pedestal Designed for Installation in Switchboard and Generator Rooms of Large Power Statioos

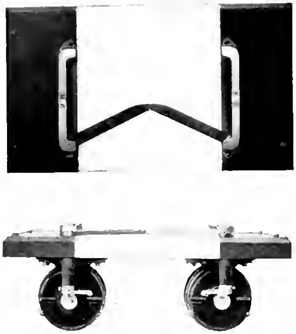
The best known use of the Selsyn system is in connection with the control of the great locks of the Panama Canal to duplicate in reduced size on a control board the movements of the lock gates and fender chains and to indicate visually at all times the height of the water in the canal and the position of the water gates and valves.

Fig. 3 shows the control board for the Gatun Locks at the Panama Canal. The marble slabs represent the parallel locks. The small chains across the slabs represent the fender chains used to prevent a vessel from ramming the lock gates; the gates themselves are shown further along across the slabs. The water gates on exterior and interior walls are represented by the stacks on the outside of and between the marble slabs, and the depth of the canal at the locks is represented by the tall chimneys shown.

The operation of the devices is as follows:

Main Gate Indicators

The main gate indicator (Figs. 4 and 5) consists of two arms each similar to one half of the main gate in the lock. Each indicating gate is hinged at its outer end by means of a vertical shaft which causes it to rotate in a horizontal plane across the marble slab representing the water in the lock. The vertical shaft is pivoted in a bearing and extends below the board. The lower end is fitted with a bevel-geared sector which engages a bevel-geared pinion attached to the rotor shaft of a Selsyn motor mounted horizontally under the board. The rotation of the motor shaft causes the gate leaf to rotate approximately 60 deg. from full open to full closed position. In the open position the leaves disappear in the covers provided for their protection.



Figs. 4 and 5. Plan and Side Views of Main Gate Indicators, Panama Canal Locks

Main Gate Transmitter

The main gate indicator (Figs. 4 and 5) is electrically connected to a Selsyn generator, mounted in a transmitting machine (Fig. 6), located at and geared to the motive mechanism that operates the main gates in the lock. The attachment is made at the upper end of the vertical shaft, which is provided with a thread that moves the rack up and down and thereby revolves the pinion which is attached to the Selsyn generator shaft. The mechanism is enclosed and protected by a sheet metal cover equipped with hinged bolts and wing nuts which make the cover readily removable.

Water Valve Indication

The construction of the water valve indicator (Fig. 7) might well be likened to that of an elevator in miniature, the car being used to show the position of the main valve in the lock walls. These indicators were built to house two distinct elements, each having its own Selsyn motor and moving equipment. The indicating element consists of a box made of thin sheet aluminum attached to an endless belt of silk fishing line passing over a set of aluminum pulleys at the top and a threaded drum at the bottom. The drum was made of aluminum also and was fastened to a hollow shaft which in turn was geared through an idler gear to the gear on the Selsyn motor shaft. The pulleys at the top were provided with an adjustable tension device, and a spring in the belt served to keep the tension uniform.

The box below the board was furnished with lamps equipped with reflectors which threw the light upward on to reflectors provided under the car. The latter reflectors threw the light out sideways against the graduated opal glass sides of the stack where it was sharply cut off by a close-fitting curtain attached to the car. Ventilators at top and bottom served to pass off the heat generated by the lamps.

Water Valve Transmitter

The indicating motor was connected electrically to a Selsyn generator (Fig. 8) which was mounted in the transmitting machine. This in its general construction was very similar to the main gate transmitting machine except in the manner of gearing to the main gate moving machinery.

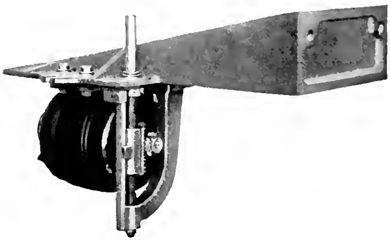


Fig. 6. Main Gate Transmitter, Panama Canal Locks

Water Level Indication

The water level indicator (Fig. 9) gives an accuracy of 1/20 of a foot. This accuracy was obtained by designing the mechanism to operate with a Selsyn motor that made approximately 10 revolutions for a 50-ft. variation of water level in the lock chambers.

The indicator was made in the form of a vertical stack whose height varied with the water levels over which indication was required. In general, the construction was similar to that of the water gate indicator except that the indicating member had four points, each of which moved over its own scale set at each corner of the stack. This made it possible to read water levels from any position at the board within reading distance.

The scales were laid off in spaces of approximately 1 in., which correspond to one foot of water.

The Water Level Transmitter

The water level indicator motors were electrically connected (see Fig. 1) to the Selsyn generators located in the water level transmitters (Fig. 10), which were mounted over the floatwells in the lock walls.

They consisted of a heavy cast-iron bracket carrying a wheel provided with spikes which shaft of the wheel was set in ball bearings to eliminate friction. One end of the shaft carried a gear which engaged another gear on the Selsyn generator located in a waterproof box attached to the supporting bracket. Thus any changes in water level were instantly

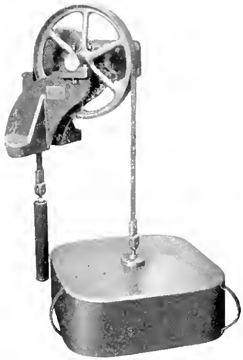


Fig. 10. Water Level Transmitter, Panama Canal Locks

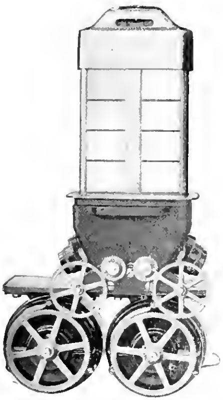


Fig. 7. Water Valve Indicator, Panama Canal Locks

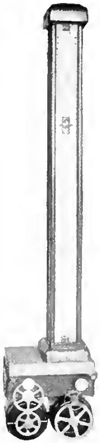


Fig. 9. Water Level Indicator, Panama Canal Locks

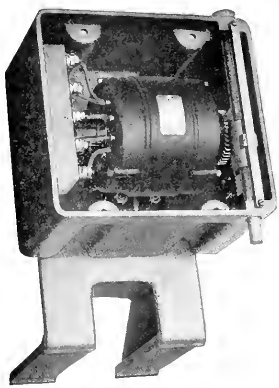


Fig. 8. Water Valve Transmitter, Panama Canal Locks

registered with holes in a bronze ribbon passing over the wheel.

At one end of the ribbon was fastened a hollow float made of sheet iron. On the other end was fastened a heavy cast-iron counterweight which kept it taut. The transmitted to the generator and recorded by the indicator at the board.

Lock Control Board for the New Orleans Industrial Canal

Another notable and interesting application of the Selsyn system of position indication will be the control board of the Industrial Canal in the city of New Orleans, which will connect the Mississippi River with Lake Pontchartrain and provide a shorter passage from New Orleans to the Gulf of Mexico through Lake Boyne. The board will be in many respects similar to the one provided for the Panama Canal and will carry indicators of the Selsyn type for ten main gates, eight water gates, and three water levels.

The indicators for the main gates will be identical with the Panama indicators except in the gear ratio between main gate moving machine and transmitters. The water gates for filling and emptying the lock chambers are single stacks. The water level indicators are lower to correspond to the difference in water level requirements.

The Selsyn System as Applied to the Control of Dry Docks

In the past dry docking operations have been conducted under the commands of a dockmaster, but lately, due to the introduction of the multiple pontoon type, there is a tendency to place the control in a central station located on shore in such position at the head of the dock that the operator may have a clear view of all the units. (Fig. 12.)

The operator can be provided with a switching and indicating board with inclined top divided into several lateral sections, each section representing a pontoon.

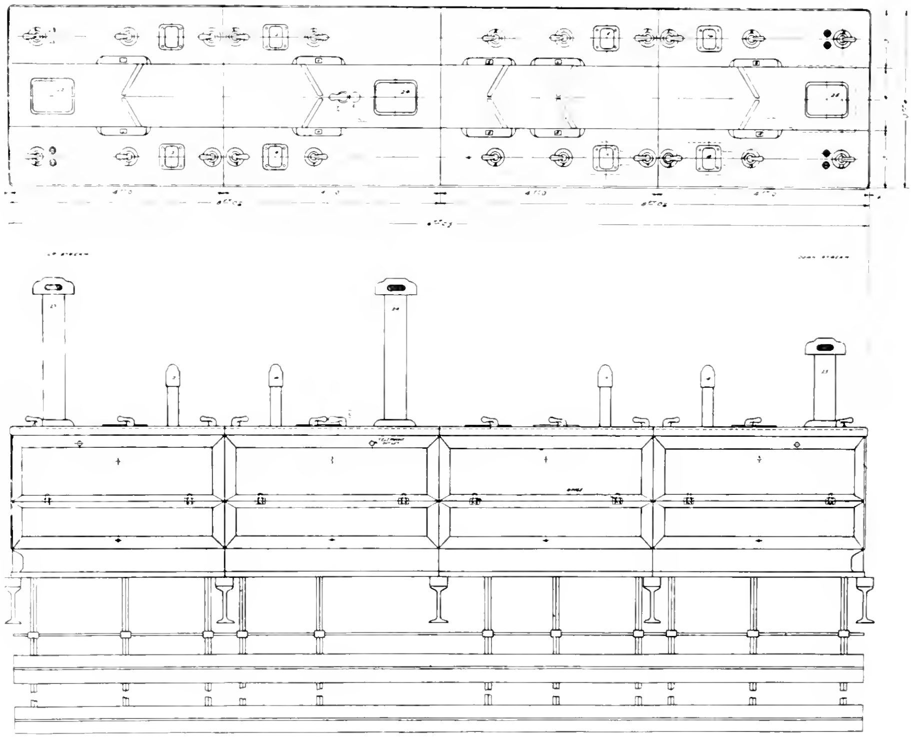


Fig. 11 Lock and Control Board for New Orleans Industrial Canal

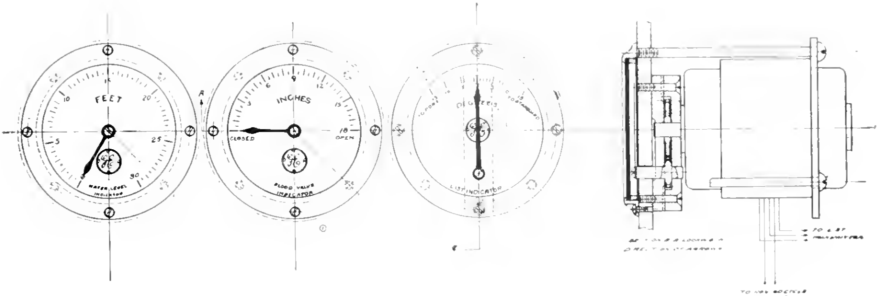


Fig. 12. Selsyn System Indicator as Arranged for Dry Dock Control

Each section can be equipped with switches for operating flood valve motors and pump motors. For purposes of accurate regulation one scheme provides on each pontoon:

6 Water level indicators,
1 List indicator, and } Fig. 14
6 Flood valve indicators.

The indicators are small devices approximately $4\frac{1}{2}$ in. in diameter and can be set nearly flush with the board

The Selsyn motors which operate them will be mounted directly under the board and connected to Selsyn generators mounted in suitable transmitting devices geared to the machines, the movements of which are to be controlled

The water level transmitter (Fig. 14) consists of a pedestal which is mounted on the deck of the pontoon. The head of the pedestal contains the Selsyn generator geared to a spiked wheel over which passes a bronze

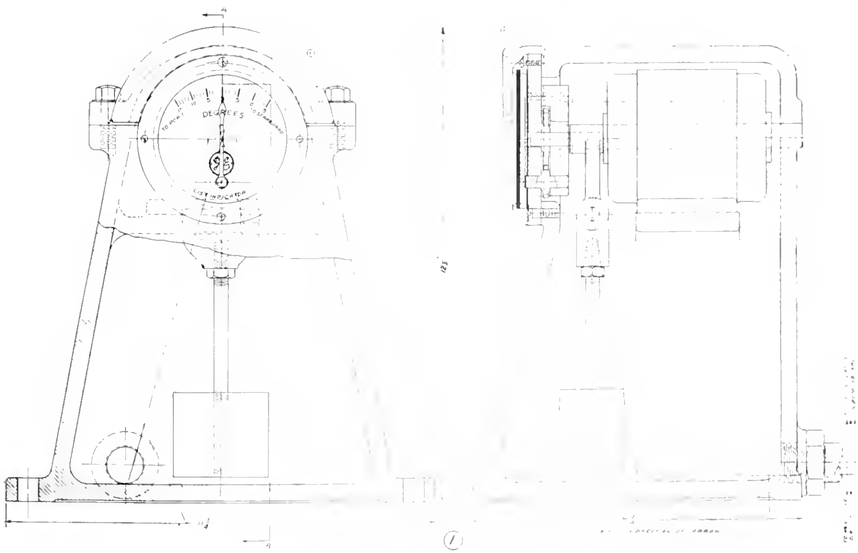


Fig. 13. Selsyn List Indicator

ribbon which is carried down through the hollow stem of the pedestal and has a float and a counterweight attached to its ends. The head of the pedestal is further provided with a dial for local indication at the pontoon in case of emergency. The list transmitter (Fig. 13) is constructed in the form of a pyramid and contains a Selsyn generator operated by a pendulum so that if the pontoon heels over in either direction the degree of list will be shown on the indicator on the control board and can be corrected by adjusting the water levels within the pontoon. This transmitter is also provided with a local reading dial, the relative reading being double the actual list for close checking.

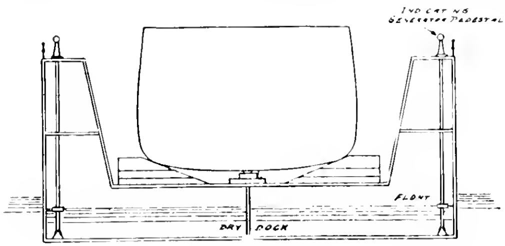


Fig. 14 Showing Location of Selsyn Indicating Generator Pedestal for Dry Dock Control

The flood valve transmitter is attached to the rotating stem of the limit switch which controls the operating motor of the flood valve machinery.

The Selsyn System Applied to the Control of Bascule Bridges

Another possible application is the control of bascule bridges from a central point. This would provide a control board having switching and indicating equipment for

1 Bridge leaf,
4 Road barriers,
8 Sets of road gates,
4 Side walk gates,
1 Center lock on bridge,
2 Rear locks on bridge,
1 Warning signal.

The indicators for all these except the signals, road and side walk gates would be Selsyn operated. Their general construction would approximate that of the main gate indicator used at Panama, consisting of a hinged leaf operating in a horizontal plane and covered with glass to prevent interference. The Selsyn operating motors would be connected to Selsyn generators in the usual manner as shown in Fig. 1.

The nature of such an installation as this makes it imperative that a certain sequence of operation be maintained, and departure from such sequence courts disaster and interruption of traffic.

To eliminate the factor of human error, it would be necessary to provide interlocking of switches. The interlocks provided on this board would be mechanical and function between the different control handles, which in this case would be always placed in such close relation to the indicator that it would be impossible to commit the error of using the wrong handle. The locking can be as follows:

The bridge cannot be opened unless:

1. Stop signal has been sounded.
2. Road gates are closed.
3. Side walk gates are closed.
4. Barriers are closed.
5. Bridge locks are opened.

Traffic on road cannot be resumed unless:

1. Bridge is closed.
2. Locks have been closed.
3. Barriers have been opened.
4. Road gates have been opened.
5. Side walk gates have been opened.
6. Go signal has been sounded.

Secondary Locking

Barriers and road gates cannot be opened unless bridge locks are closed. Road gates cannot be opened unless barriers are open. Go signal for road traffic cannot be sounded unless road and side walk gates are open. Bridge locks cannot be closed unless bridge is closed. Bridge cannot be opened unless locks are open. Road and side walk gates cannot be closed unless stop signal has been sounded.

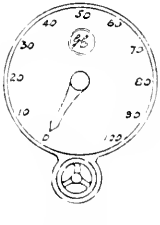


Fig. 15. Selsyn Indicator for the Operation of Bascule Bridges

Selsyn Kilowatt Load Indicator

In large power stations it has been found advantageous to have a method of transmitting periodical load requirements in advance to the generator and boiler rooms. For this purpose there has been devised an arrangement of Selsyn indication closely resembling the switchboard signal system previously described, with the difference that the indicator is made with a large dial approximately 3 feet in diameter for mounting on the wall or other conspicuous location.

The dial is provided with suitable numbers covering the maximum and minimum output and all conditions between. The transmitting elements may be mounted in any convenient location under the control of the proper authority for transmitting the information.

Standard Geared Selsyn Generator

An important step toward standardization has recently been made in the development of a geared Selsyn generator that is applicable to many conditions. This is shown in Fig. 17 and consists of a shell somewhat in the shape of a motor frame. This shell contains mounting for a Selsyn generator, together with gearing and provision for changing gear ratios without affecting the general design.

At one end of the device a main shaft is brought out which forms the attaching point to any piece of machinery that requires indication, through the medium of spur or bevel gears or a sprocket and chain. The front of the device may include a dial for local indication.

The Selsyn System for Motor Drives

Conditions sometimes require the use of Selsyn control on devices which the Selsyn motor cannot handle on account of lack of power. To meet such conditions there is being developed a system in which the Selsyn motor is made to do the contacting for switches that operate the circuits of a separate motor capable of handling the machinery. The switching may be so arranged that the motor will be operated in either direction under the control of the Selsyn motor.

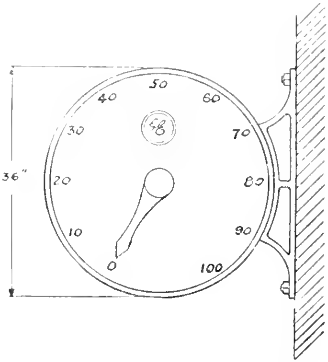


Fig. 17. Geared Selsyn Generator for Miscellaneous Purposes

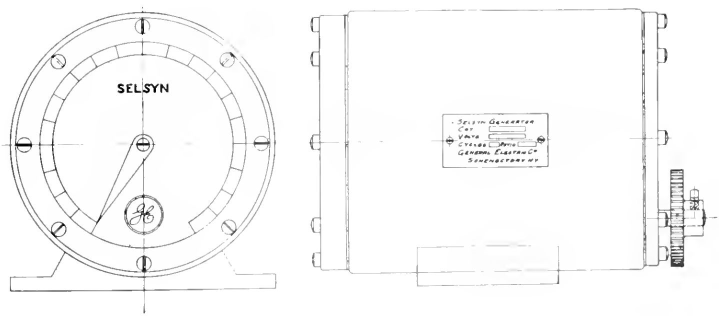


Fig. 16. Selsyn Power Demand Indicator for Generator Room and Boiler Room. These indicators show anticipated power requirements

Conclusion

Where it is desired to show the movement or position of a device at a distance, the Selsyn system is very useful and the field of application is quite extensive as previously explained. The method consists of gearing a Selsyn generator to the device, the movement of which it is desired to indicate, thus transposing the motion of the device into a circular motion.

The Selsyn motor used as a receiving device duplicates this angular motion and is geared to a receiver indicator of the form that is desired, either a duplicate in miniature of the device to be indicated or a circular or other scale with suitable divisions.

The angular motion can be shown on an indicator to represent the distance a valve is opened, as in the case of water levels in tanks, vats, stand-pipes, reservoirs, etc. The amount of opening of water valves or steam valves can also be indicated. The position of a weather-vane on a suitable tower can be shown in miniature, the vane being located at a convenient place for the observer. The rudder position can be transmitted from the rudder to an indicator located in a convenient position for the helmsman.

The Induction Disc Phonograph Motor

By Chester I. Hall

Experimental Laboratory, Ft. Wayne Works, General Electric Company

Several makes of small commutator-type motors have been placed on the market for driving phonographs. Virtually all of these motors are arranged to operate in a vertical position and drive the phonograph disc by friction through a small pulley mounted on the lower end of the motor shaft and bearing against the outer edge of the disc. The phonograph motor described in this article is of an entirely different form and has decided advantages over other types in the matters of starting torque and speed regulation. The principle is essentially that of the induction type watthour meter. A prominent phonograph company has planned to incorporate this motor as standard equipment on its line of machines.—Editor.

The final solution of the problem of building a satisfactory electric motor for phonograph drive is dependent upon three fundamental characteristics, viz.:

(1) Silence
(2) Speed control
(3) Reliability

In reviewing the various available types of electric motors, it was apparent that one of them approached the ideal much more closely than any of the others. This form has had no definite name because of its limited application, but for purposes of clearness will be called the induction disc type.

An induction disc motor consists of four essential parts: the stator magnetic circuit, energizing coils, phase splitting parts, and the disc rotor of non-magnetic material. The first three elements are necessary in order to create a flux of two component parts out of phase with each other, thus generating what is known as a shifting alternating-current field. Part of the flux is used by induction to generate currents and magnetic fields in the disc in such a way that the interaction of the disc and field causes torque.

Motors of this type have been used for some time in measuring instruments where accuracy of performance is essential, but they have been sadly overlooked as small power units where special characteristics, inherent in their type, make them very useful.

Torque

The torque-speed curve is given in Fig. 1. It is a straight line starting at maximum torque at standstill and finishing at zero torque at maximum speed.

Speed

The maximum speed is determined by the ratio of the torque to electro-magnetic damping. The no-load speed is generally low, seldom over 300 r.p.m. The speed under load is determined by the amount of torque necessary; the greater the load the lower the speed.

Power

This type is essentially a small power motor on account of its low speed and poor efficiency. A power-speed curve is shown in Fig. 1. The power is always a maximum at half of the free speed, and is of course zero at standstill and maximum speed.

Frequency

Since this is an induction motor, it is directly affected by a change in frequency.

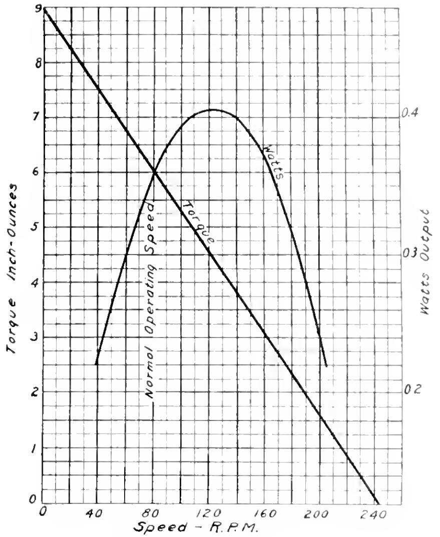


Fig. 1. Speed-torque and Power Curves of the 110-volt 60-cycle Disc Phonograph Motor

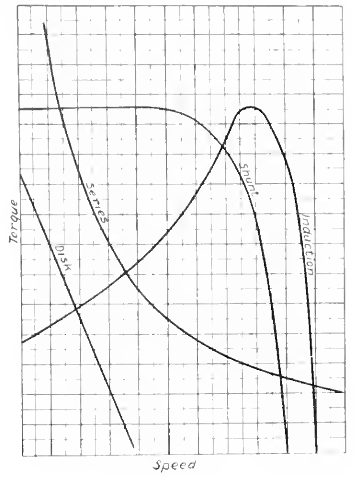


Fig 3. Speed-torque Characteristics of Various Types of Motors

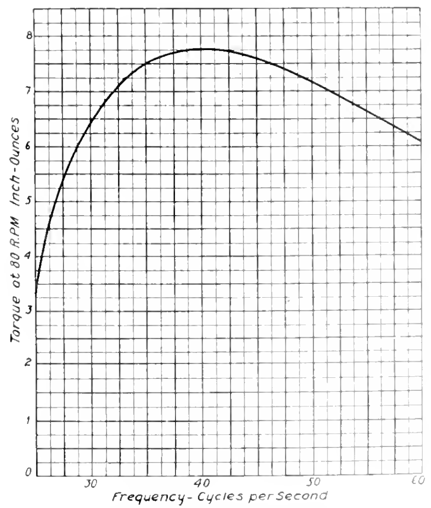


Fig. 2. Torque Curve of the Disc Phonograph Motor at 80 R P M. 110 Volts and Frequencies Between 25 and 60 Cycles

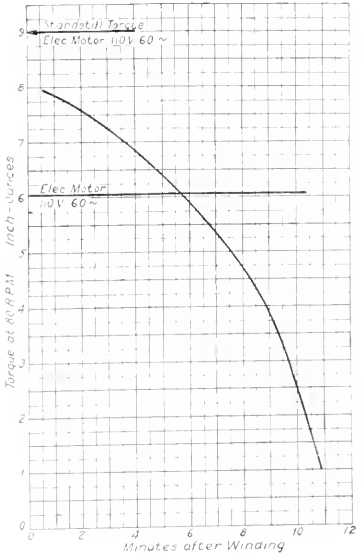


Fig. 4. Torque-time Curve of Electric Disc Motor and Spring Motor

Fig. 2 gives a frequency-torque curve for a phonograph motor maintained on constant voltage. This motor was designed to operate at 60 cycles. The torque reaches its maximum at 40 cycles on account of a much larger input than at 60 cycles. It decreases

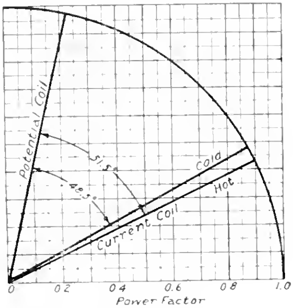


Fig. 5. Phase Angles of Potential and Current Coils at 60 Cycles

at lower values because the effectiveness of the frequency is falling off at a greater rate than the increase of input. At the higher values the input is decreasing more rapidly than the increase of effectiveness of the frequency. A given motor may be operated over a considerable range of frequency provided the minimum torque is sufficient to carry the load.

For purposes of comparison, the curves of Fig. 3 have been drawn, showing the speed-torque characteristic of various well-known types of motors, and also that of the induction disc. If these characteristics are carefully studied, the application to phonograph motor drive will be quite obvious.

The photographs give a general idea of the mechanical design and arrangement of the parts. The motor consists of a rotor mounted on the main shaft, the upper end of which supports the turntable carrying the record. This rotor consists of a ring of copper about 9 in. outside diameter, and is supported on a cast aluminum spider. The rotor ring, which is about $1\frac{1}{2}$ in. wide, revolves through a shifting magnetic field produced by field coils wound on laminated magnetic circuits similar to those in an ordinary watt-hour meter as regards shape, size and method of producing the shifting field. Thus, with the torque-producing element directly on the main shaft, all necessity for high speed gearing, belting, or friction drive has been entirely eliminated.

The main shaft is supported in an adjustable hardened steel ball thrust bearing in

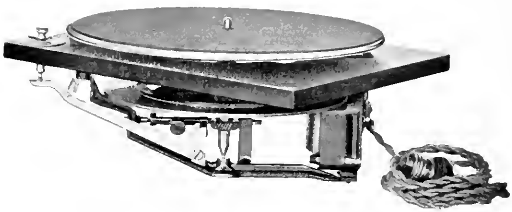


Fig. 6. Three-quarter View of Motorboard with Turntable

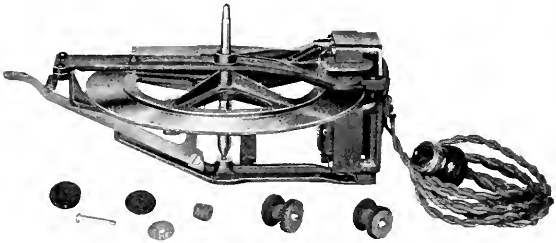


Fig. 7. Three-quarter View of Motorboard Without Turntable

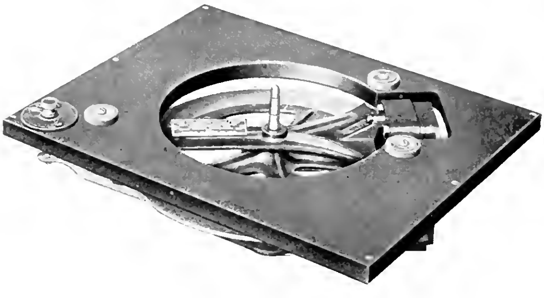


Fig. 8. Top View of Phonograph Motorboard

the lower bracket, while it is held in place by a guide bearing of phosphor bronze in the upper bracket.

The lower bracket also supports a governor of the conventional type, which is geared to the main shaft by a silent worm wheel. Reference to Fig. 1 will show that the motor exerts maximum torque at standstill, which gradually decreases with increasing speed to the free-speed no-torque condition. This type of curve is particularly suited to phonograph service, since quick acceleration and good speed regulation are possible. Any tendency to slow up while running is counterbalanced by an increase in torque, resulting in very close speed regulation under widely varying loads.

Considerable difficulty was experienced in eliminating the magnetic hum, due to the 60-cycle circuit, but this was finally accomplished by a proper design of the supporting brackets and spider, as well as by the elimination of vibration in the motorboard itself. It was found that an aluminum spider was very much quieter than a cast iron spider when supporting the same weight of disc.

In the final arrangement the motor was suspended from the motorboard by three screws to the upper bracket. These screws were surrounded by sponge rubber bushings and washers in the motorboard and made transmission of vibration from the motor to the board very slight.

The outstanding advantages of this form of electric phonograph motor are:

First, due to its extremely simple construction (only two moving elements), its stationary windings, and the elimination of commutator and other sliding contact, there is no successful competitor for reliability.

Second, the very small amount of power absorbed in bearing friction not only makes this design very effective with regard to weight and power consumption, but gives it a life which is probably limited only by deterioration of the insulation.

Third, the motor has been built and attached to the board as a unit, making it completely interchangeable with the spring motor, and weighs only 7.69 pounds as against 10.88 pounds for the spring motor.

Fourth, no damage to the rotor or windings or increase in watt loss results from stalling the motor under full voltage, so that the ordinary type of friction brake may be used.

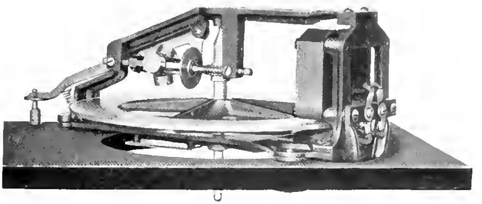


Fig. 9 Side View (Inverted) Showing Terminal Arrangement and Governor

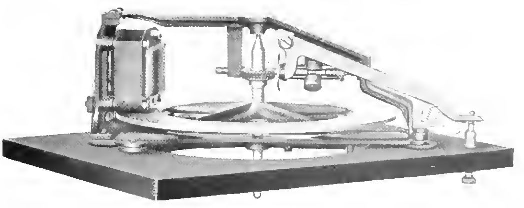


Fig. 10. Side View (Inverted) Showing Speed-control and Windings

Photo-elasticity for Engineers

PART IV. THE USE OF PHOTO-ELASTIC METHODS IN THE DESIGN OF THE ELEMENTS OF MACHINES AND STRUCTURES

By E. G. Coker, D.Sc., F.R.S.

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Written specially for General Electric Review

In this article the author applies the photo-elastic method to the subject of mechanical design. A method of procedure is suggested and illustrated by application to the design of an eye bar. Some advantages of this method of design, over the old, are enumerated.—Editor.

The main subject matter of this chapter is the consideration of the problem of the design of machines and structures, a much more difficult field of inquiry than any which we have yet had to consider, and in which one feels greatly daring in presenting any views whatever.

This subject is, however, one of the primary factors on which the success of all engineering operations depend; but when one attempts to say what are the essential elements which make for success in design, it is difficult to give a full and complete answer. That this kind of ability is fairly widely spread we all know; that it can be cultivated to a high degree of perfection is very apparent to those who have had engineering experience; but there still remains something more or less intangible, which differentiates the first class man from the super-designer, who combines knowledge, experience and skill with an intuition for picking out the best of all possible methods in so complete a fashion that the blend of all these cultivated and inherent faculties enables him to evolve a well nigh perfect machine or structure.

Such men are rare, but those individuals in whom we recognize this skill, almost akin to genius, all seem to possess that same craving for scientific knowledge which distinguished the early pioneers of engineering, like Watt, Stephenson and Faraday; and although it is not possible for the many to emulate the example of these historic figures, yet we are all in a sense more fortunate than they were since the facilities for obtaining all kinds of scientific knowledge are now so great as compared with the past.

Photo-elasticity is one among many sources of knowledge on which engineers can rely for information regarding stress distribution and although as yet but small attention has been given to its application to design, it appears possible that its use may in the future be greatly extended until it becomes a recognized drawing office and workshop method for determining the forms and proportions of the different elements which make up a machine or structure.

One of the chief difficulties usually met in designing is the defect in our knowledge of the data affecting the problem, which latter cannot in general be stated exactly. This is particularly noticeable with running machinery, where the effects of varying load, pressure and temperature changes, friction, wear, inertia of moving parts and the like are difficult to estimate, while the necessities imposed by manufacturing processes complicate the problem still further.

Many of the processes of design appear to commence from the assumption of a definite form, the scale of which is adjusted by the conditions to be met, and it would no doubt be an advantage if the process commenced at an earlier stage with a systematic attempt to find the most suitable shape. In this work photo-elasticity can be pressed into service provided it is borne in mind that it can only be of use in one element of the problem, viz., as regards stress distribution.

If the design of an element is assumed to depend primarily upon the load which it has to bear we are at liberty to adopt any criterion which appears likely to attain the required end, and our judgment of its value will depend upon the results obtained.

If, by way of example, the simple case of a tension member is taken, in which a pull is transmitted by pins at each end, then it is clear even without any examination in the polariscope that a rectangular plate such as is shown in Fig. 1 is not a good form, since in the main body of the member the stress is much less than in the neighborhood of a pin. Economy of material with a more even distribution of stress will be obtained if the outline is modified somewhat as shown by the dotted lines, so that the main section of the link is fixed by the ability of the material to withstand the tensional load without overstress, and the end contours so designed that they shall not be stressed beyond the capacity of the material at any place.

This particular problem has exercised the minds of engineers in all parts of the world, notably those having to do with bridges, and many diverse forms have been used as main tension members, showing that no general agreement has been reached in this simple case. Some of the well known standard shapes appear to have been assumed in a perfectly arbitrary manner, or at the dictates of manufacturing necessities, and their scale determined by experiments on links tested to destruction.

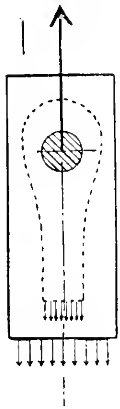


Fig. 1

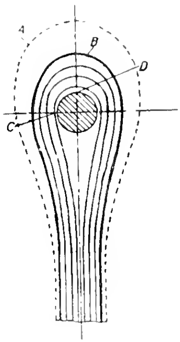


Fig. 2

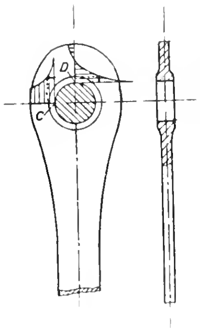


Fig. 3

If, however, a commencement is made by the aid of a definite principle, one which appears to be helpful is to shape the contour by following the lines of principal stress subject to whatever initial conditions it may be necessary or reasonable to impose. In this example if the distance between the pins is considerable, the main body of the member may clearly be taken as of uniform cross section, and the shape of its ends determined by tracing the directions of the lines of principal stress in a plate shaped in such a fashion that the temporary boundary of the end allows free development of these lines. If for example the temporary contour has the form of a curve A, Fig. 2, having the line of load as an axis of symmetry, then a new contour B can be obtained experimentally which is everywhere tangential to one of the systems of principal stress, and which may be taken as an approximation to the shape sought. Experiment shows that the arbitrarily chosen form of the contour A influences the form of the contour B, especially if the two are close together, and for this reason alone it appears to be desirable to begin by choosing an ample boundary in order to obtain curves of principal stress not much influenced by the primary contour conditions. Having in this manner obtained a number of possible boundaries, one of these can be chosen and the plate cut to this form for further experiment. An examination of this form in the polariscope shows a picture of the stress difference through the member, and what is in general of particular advantage, the actual stresses at all parts of the boundary wherever there are no external loads—a result of much use in a rapid investigation. In any case, however, a complete analysis can be made of the stress in a plate fashioned in this way. It may happen that the shape so chosen may be altered by following an interior principal stress line to obtain a further contour which can be examined anew, and it is of importance to point out here that such a process has the effect of reducing all the stresses *across* the new contour to zero.

From a purely theoretical aspect it would seem proper only to cut a new contour along a line of principal stress in which the cross radial stress is zero, but in general this is not possible. By proceeding in the fashion described, it has been found possible however to arrive at a form which shows a distribution of stress which compares very favorably with that of any of the existing forms, its principal characteristics being the more gradual merging of the main body of the member into the end, as Fig. 2 shows, with lessened stress concentration and the absence of any circular curves in the external contour. Even with all the care, however, which can be taken it is impossible to avoid great concentration of stress in a plate link at various points, and these places are especially noticeable near the inner point C of the transverse cross section and slightly below this plane where the largest tensional stress is visible, and also at the inner point D

of the longitudinal section. The stress distribution across the sections is, in fact, somewhat as indicated in Fig. 3, and it can be reduced, where most intense, only by increasing the cross section of the link around the pin. This may be accomplished when a safe working stress is chosen by marking off a line showing this intensity on the stress distribution diagrams as indicated, and determining the thickness and radius of a boss which will approximately reduce the stress to a proper value. If necessary the distribution caused by the bosses may be examined in the polariscope and new dimensions found by further experimental measurements. As regards this particular problem it may be remarked that although pin-connected tension members do not occupy the importance they once did in bridge construction it is possible that it may be still necessary to use such members in the very largest span bridges of the future, and a detailed investigation of the form to be given to the ends, for the most economical weight, would then be well worth while. For simple eye-bolt connections where lightness is of extreme importance, as in airplanes, the same methods might also be employed, especially as the methods of reducing the stress around the pin, advocated here, would be more justifiable than for a very large member such as is used in bridge work.

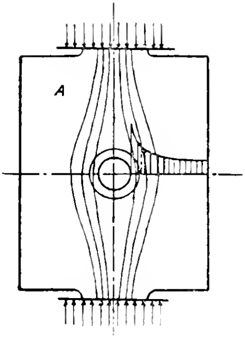


Fig. 4

Although the choice of the directions of principal stress in selecting a contour may be questioned, there is some evidence for its use afforded by nature which may be adduced in its support. If the bone structure of the human frame is examined it is found that the directions of the tissues of the interior form frameworks which follow the lines of principal stress resulting from the loads applied to them at the joints, and this appears to be true not only for man but also for the whole of the animal creation now existing or belonging to past eras. One of my colleagues, an authority on paleontology, informs me that the lines of principal stress in fossil bones afford a valuable indication of the mode of locomotion of the creature to whom they belonged. Even, however, if the criterion adopted here is not the correct one, it is possible to demonstrate in many cases that it does give shapes which prolonged experience shows to be correct after possibly a long process of elimination of bad forms which have failed to stand up to their work.

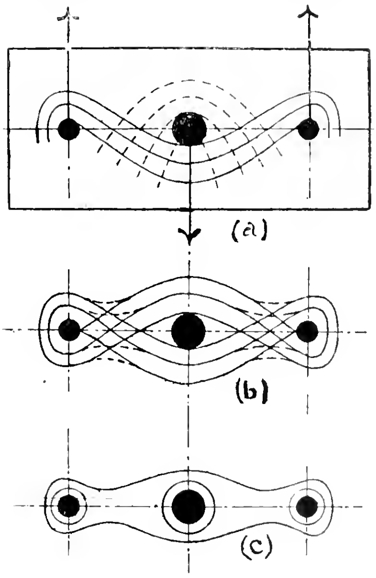
As a further instance of the application of photo-elastic methods to design we may take a compression member having a central hole in it which as we know causes a great concentration of stress around its boundary when load is applied. Commencing with a rectangular plate, it is easy to determine the lines of principal stress which start from the application of load at one end, pass around the hole and arrive at the opposite loaded contour. Some of these curves are shown in Fig. 4, and the distribution of stress across a horizontal section is indicated; from which by a further selection of new contours and a re-examination of the problem it is possible to determine an economical form in which, as before, some definite addition of material around the hole is necessary according to the stress distribution determined in this region.

A good many attempts at design have been made in this way, and it is only proper to say that not all have been successful. There are difficulties in some cases of which one or two may be indicated in an attempt which was made to design an ordinary straight lever with equal arms.

Adopting an ample contour, in this case a rectangle, Fig. 5a, and applying appropriate forces to the pins as indicated, it is not difficult to draw on the projected image of this primitive lever a series of curves of principal stress by aid of a plane polarized beam in the polariscope.

One set, mainly lines in tension, indicate a primitive shape for the lever, and the other set, shown dotted in Fig. 5a, must, however, be regarded as redundant in this problem. The first set are clearly called into being by the circumstances created by the directions of the loads at the pins, and if these directions are reversed, all these lines re-appear on the opposite side of the center line, and for both sets we obtain curves of the form shown in the second figure, where a new difficulty presents itself by the intersection of the two families of curves.

The obvious way of evading this difficulty is to add transition curves Fig. 5b at these angles, as indicated by dotted lines, and then re-examine the new model cut from the outer contour. If this process is carried out, so far as may be necessary, and the places of greatest stress in the plate strengthened by adding bosses at the pin contours, by the methods already indicated, a final form is derived, as Fig. 5c indicates, which is not inconsistent with those used in practice where conditions of work have led to great care in the design of such levers.



Figs. 5a, 5b, and 5c

The method in this case, however, is open to criticism. It must be admitted also that in some cases, particularly hooks and curved links of chains, it has not yet been found possible with this criterion to produce a design which gives results which practice has shown to be desirable or necessary. Although the criterion adopted may possibly not be the most suitable one for the purpose, yet the cases described show that it does give shape and form to some simple members which are not inconsistent with independent experience.

Whatever view may be taken on this matter there still remain many advantages in experiments on transparent models which are quite independent of this particular system of design, and in fact, a purely arbitrary procedure, such as a method of trial and error, can be used until a suitable shape is evolved with much greater ease and rapidity than any other method known to the lecturer. The polariscope indicates the stress distribution at all points by the stress-differences (P-Q) existing in the material, and as shear is proportional to this difference we have at our command pictures representing shear stress for any body capable of being represented by a model in plate form.

This is particularly convenient for many engineering purposes because experiment shows that ductile materials like mild steel, wrought iron, brass and the like fail when the shear stress passes a limiting value, and hence the color pictures of the polariscope afford a ready means of finding places under high shear stress, that is, where failure is likely to occur.

The mechanical properties of nitro-cellulose also warrant the belief that this material also fails by shear unless of exceptional hardness, so that wherever failure occurs in a model we may look for a similar occurrence in the actual member in ductile metal.

As regards brittle metals, experimental evidence appears to favor the view that breakdown occurs when the major principal stress reaches a limiting value, and in such cases it is probable that the behavior of models in glass would represent most accurately the conditions in cast iron and the like, but so far there appears to be little exact experimental evidence owing to the difficulties of shaping glass for this kind of experimental work. As regards all forms of nitro-cellulose examined so far, the points of failure are particularly easy to locate, since breakdown of the structure shows itself by a clouding of the color bands, and the ultimate formation of a black patch in the over-stressed area which on the removal of the load shows its presence by its persistence when stress intensity has been carried far enough to break down the internal structure very much. If only a small overstress has been experienced the removal of the load causes these places to appear as white patches when contrasted with the dark field of the rest of the model as viewed through crossed Nicol's prisms.

From what has been said it may be inferred that experiments with transparent models yield information which can only be obtained with great difficulty, if at all, in a metal, and that little time is required to obtain the information described as compared with any other known experimental method.

A design of a suitable form for a plane member under stress may, in fact, be carried out usually with considerable rapidity and at small cost.

It is also worthy of note that whether this is carried out by the criterion of principal stress lines or not a characteristic feature which presents itself is the almost complete absence of straight lines and circles in the form found, and there seems to be few cases in which these may be properly used in cases where complex stress occurs in the material. The examples which have been described indicate this clearly and there is good reason to think that the accidental circumstance that straight lines and arcs of circles are easier to draw than any other curves often leads to failures in the material when under stress, which were it not for the somewhat slavish adherence to the usual drawing instruments might be avoided by a more rational procedure.

(To be continued)

Switchboard Equipment for Cape Town

By Emil G. Bern

Switchboard Engineering Department, General Electric Company

The switchboard and control equipment described in this article embodies the very latest engineering features and practice. The control board is remarkable for its size and for the complete provisions that are made for present and anticipated future requirements. The capacity of the generators and transformers which it will ultimately control will be several times that which will initially be put in service.—Editor.

In building their new Dock Road power house, the Corporation of the City of Cape Town, South Africa, has looked carefully into the future and has planned for almost any conceivable demand for electric light, power and railway service. At least as far as the switchboard equipment is concerned, judicious provision has been made for the most optimistic expansion without impairing the logical arrangement of equipment or continuity of service. The installed generating capacity is somewhat less than 20,000 kw., but the switchboard has been designed to handle many times this amount.

System of Connection

Fig. 1 shows the system of main connections. The standard frequency is 50 cycles. Two operating voltages are generated and maintained, viz.: 11,000 volts, 3-phase, 3-wire for synchronous converters, large motors, and for distant distribution; and 2200 volts, 2-phase, 3-wire for motor-generators, medium size motors and for local distribution. The two phases of the quarter-phase system are interconnected through a common bus, which is grounded. The 11,000-volt generators are Y-connected, with the neutral point grounded for protection. The high and the low tension buses can be connected through Scott-connected transformer banks, operative in either direction. It is therefore possible to deliver current at 11,000 volts 3-phase, and 2200 volts 2-phase with any single machine, or with any combination of machines running.

Double sets of buses are used on both systems to eliminate interruption of service at times of cleaning, repair or extension. Each circuit has a single oil circuit breaker for the two sets of buses, but bus tie oil circuit breakers are installed for connecting the two sets when desirable to transfer a circuit from one bus to another. The same arrangement is used on the 11,000-volt and on the 2200-volt systems.

Automatic Protection

The generator circuits are protected by time-limit overload relays of the induction type. Instantaneous differential relays are connected through current transformers across each phase of the generator windings. These are hand reset. In the ground connection of the 11,000-volt generator there is also an instantaneous overload relay.

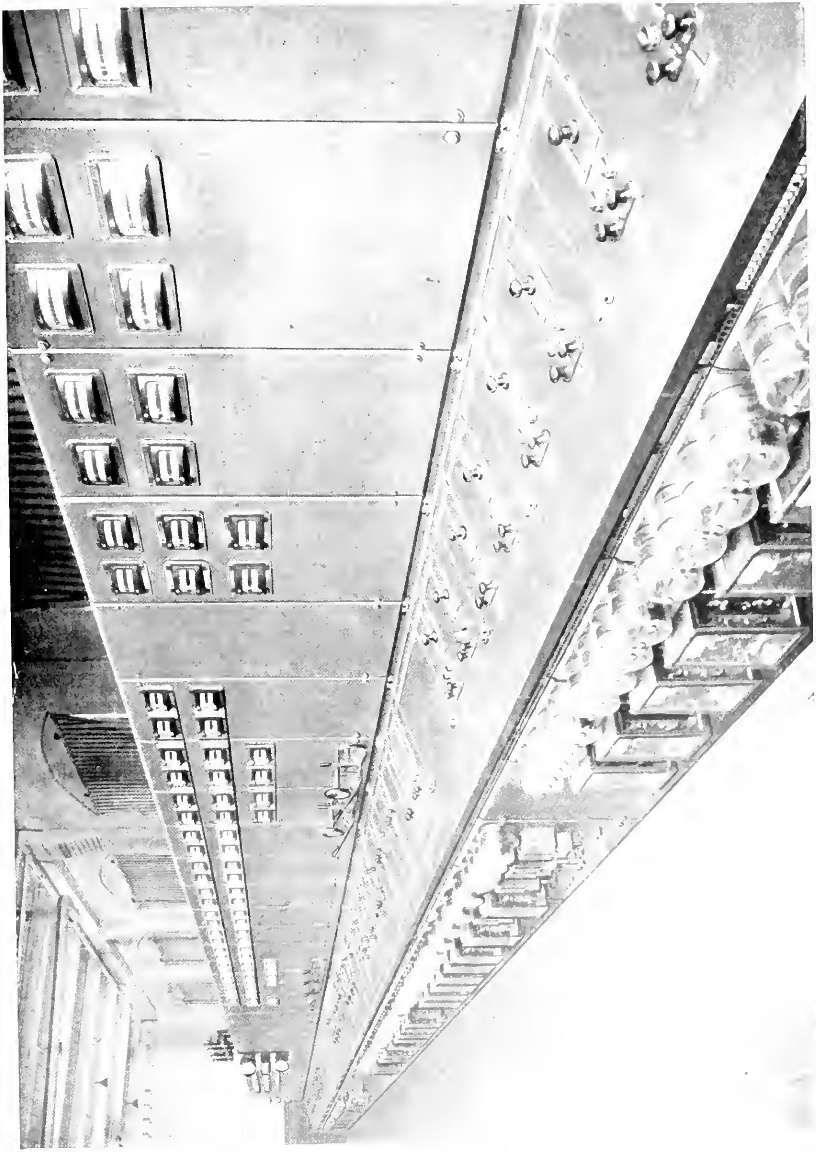


Fig. 2. Instrument and Control Board for Cape Town, Africa. This switchboard is more than 100 ft. long, and while it controls at present only 20,000 kw., provision is made to handle several times this capacity

The 3-phase to 2-phase transformer circuits have time-limit overload relays, and also instantaneous differential protection across the transformers.

All feeders and the bus tie circuits have time-limit overload protection, the 11,000-volt feeders each having in addition an instantaneous relay operating to open the circuits on unbalanced load.

Besides this protective equipment each circuit is provided with a so-called trip free relay, the function of which is to allow an electrically operated circuit breaker to open automatically immediately on closing, even if the control switch should not yet be open; or in other words, to prevent holding a circuit breaker closed on an overload.

Switching Apparatus

Fig. 3 shows the arrangement in cross section of switching apparatus. The oil circuit breakers are General Electric standard "H" type, motor operated. This type of oil circuit breaker favors a very simple arrangement of the bus compartments and disconnecting switches. Doors are hung in front of the compartments for protection. A masonry wall between the two sets of buses on both the low tension and high tension systems serves as a solid support for the disconnecting switches, as a carrier between different parts of the system in case of short circuit trouble, and as a perfect protection against danger during cleaning, repairs, or when making extensions.

Instrument and Control Board

Fig. 2 shows the instrument and control board as assembled in the factory before shipment. The construction is General Electric standard, with some special features to meet certain requirements of the installation. The length of the board is over one hundred feet. The ends between the board and the wall are enclosed with grille work and doors. A mimic bus and connection system finished in dull copper is laid out on the control bench to represent diagrammatically the main connections of the station. The oil circuit breakers are represented in this diagram by the control switches which operate them, and the generators and transformers by name plates properly inscribed. The contrast of the dull copper finish on the natural black slate presents a pleasing appearance.

A signal system for communication between the switchboard and the machine is provided for each unit. The machine station is pedestal mounted and located near the machine, and the switchboard station is set into the control bench from which the machine is controlled. Each signal station is complete for sending, receiving and acknowledging six signals. A three-way push-button switch lights a lamp back of the

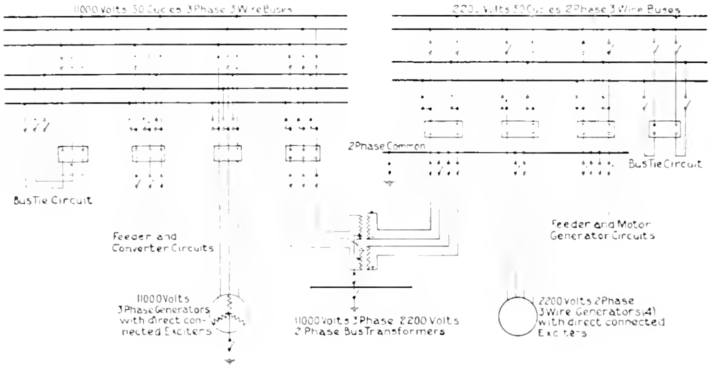


Fig. 1. Diagram of Main Connections

signal word etched on a glass plate; and an alarm bell rings until the signal is answered by turning the light off.

The specifications and designs for the switchboard equipment were prepared jointly by the engineers of the General Electric Company and Geo. H. Swingler, city electrical engineer of Cape Town.

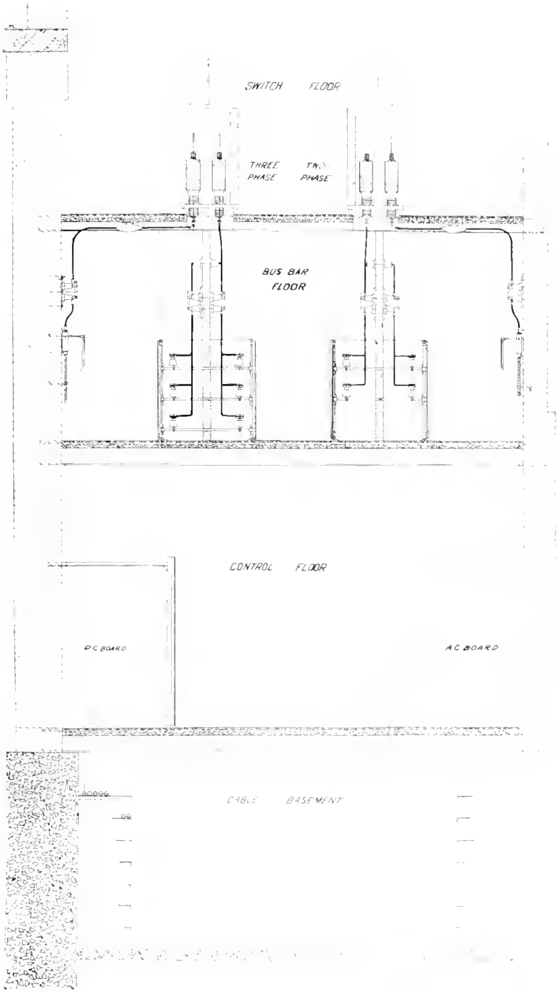


Fig. 3. Sectional Elevation of Control Station, Showing Location of Oil Switches, Buses, Control Board and Cables

Shipyard Cranes

By H. H. Vernon

Power and Mining Engineering Department, General Electric Company

The record breaking pace set by the intensive wartime program of our Emergency Fleet Corporation would have been impossible without the electrically-operated shipyard crane. Equally indispensible is this type of crane in the economical construction of ships in times of peace. In assembling a ship on the ways, the electrically-operated crane handles the great variety of heavy and clumsy parts with a dexterity that is almost human and, what is of particular value, does so at the high all-day efficiency characteristic of electric drive for intermittent duty.—Editor.

In ship construction, practically all the material is so heavy or unwieldy as to require its being handled and placed in position by mechanical means. For this purpose the electrically-operated crane is employed and therefore ranks as one of the most important pieces of machinery in the shipbuilding industry.

There are different types of cranes used for different classes of service, and in some instances there are two or more types which are utilized for the same class of service. This article however is restricted to a description of the more common varieties of the outdoor type because the indoor cranes used in shipyard foundries, forge shops, and machine shops are the same as those found in similar service in other industrial plants.

Shipyard cranes range widely in size and character, the limits being the small hand-operated device for handling light loads and the exceedingly large 350-long-ton hammerhead electrically-operated fitting-out crane* shown in Fig. 9. The most common type is the jib-boom crane, of which there are a number of different models as shown in Figs 1, 2, 3, 4 and 5. The one shown in Fig. 3 is of the swing-boom or derrick class and has only three motions: hoist, boom hoist, and swing. If cranes of this design are employed to cover a shipway of any considerable size, a large number of them will be necessary because the area served by each crane is limited to the length of its boom and therefore their spacing must be sufficiently close to permit the end of each boom meeting the end of the boom of the adjoining crane.

Figs. 1, 2, 4 and 5 illustrate cranes of the traveling jib-boom type, that is, in addition to having hoist, boom hoist, and swing motions the crane travels on a track or runway. As these cranes run back and forth the entire length of the shipway, only one is necessary on each side of the way or one crane will serve adjacent sides of two ways. A traveling jib-boom crane serves a large

* A description of this crane appeared in the June 1920, General Electric Review

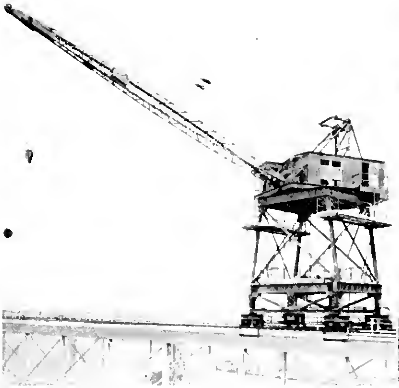


Fig. 1. Revolving Jib Traveling Crane. New York Shipbuilding Corp., Camden N J.

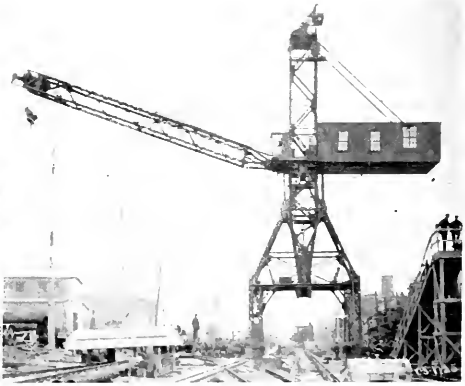


Fig. 2. Revolving Jib Traveling Pillar Crane. Merchant Shipbuilding Corp., Bristol, Pa.

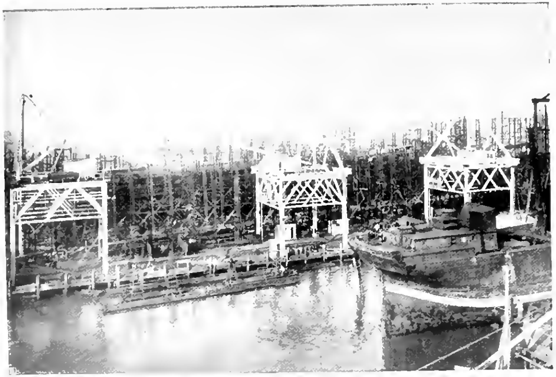


Fig. 3. Stationary Cranes of the Swing-boom or Derrick Type. Moore Shipbuilding Co., Oakland, Cal.

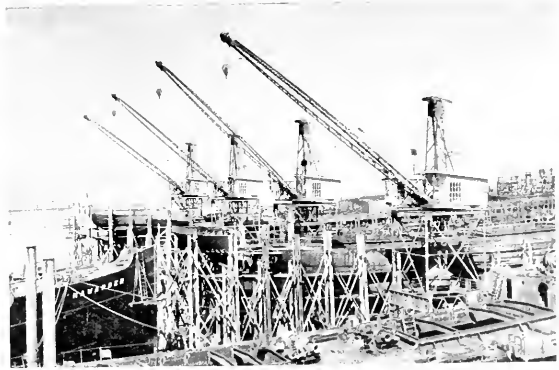


Fig. 4. Revolving Jib Traveling Cranes. Union Construction Co., Oakland, Cal.

Fig. 5. Revolving Jib Pillar Stationary Cranes. Harlan Plant, Bethlehem Steel Co., Wilmington, Del.

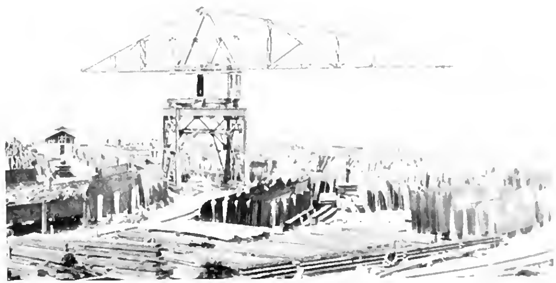


Fig. 6. Traveling Hammer-head Crane. Union Construction Co. Oakland, Cal.

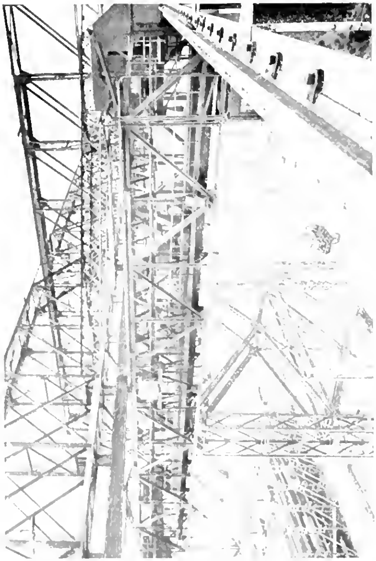


Fig. 7. Traveling Bridge Crane Over Ship-ways. Newport News Shipbuilding & Dry Dock Corp., Newport News, Va.

Fig. 8. Gantry Crane. Newport News Shipbuilding & Dry Dock Corp. Newport News, Va.

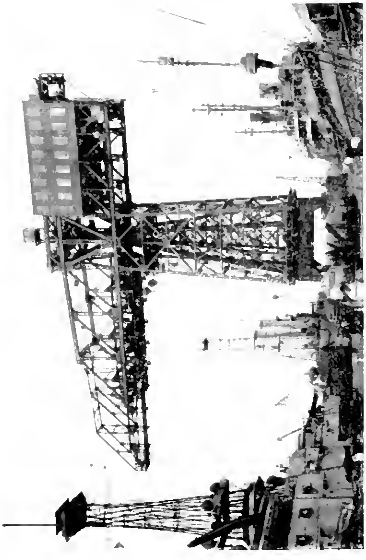


Fig. 9. Revolving Hammer-head Crane. League Island Navy Yard, Philadelphia, Pa.

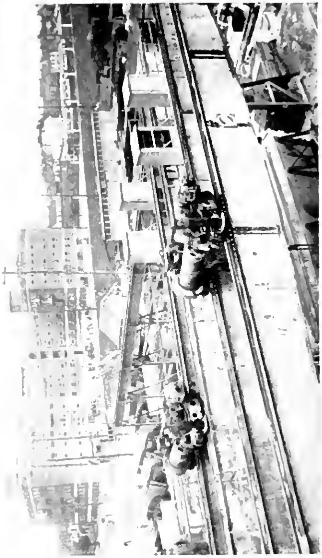


Fig. 10. Traveling Bridge Crane. Newport News Shipbuilding & Dry Dock Corp. Newport News, Va. (Note houses for control panels)

area, limited only by the length of the boom and the length of the runway. As shown by the illustrations, some of these cranes run on a track laid on the ground while others run on an elevated track.

Fig. 4 shows cranes of the turn-table and king-pin type, and Fig. 2 one of the pillar type. The former has the turn table or revolving part held in position by a king pin and the weight is supported on small wheels or rollers. The latter uses a pillar instead of a king pin and the weight of the revolving part is supported on small wheels or rollers or on a spherical bearing at the bottom. When supported on small wheels or rollers the lower end of the pillar is held in place by a vertical bearing which takes the side thrust.

While the foregoing types comprise those most commonly employed, some others used in shipyards are of the hammer-head, half-gantry, gantry, and travelling bridge types. The hammer-head crane is made either stationary as shown in Fig. 9, or movable as shown in Fig. 6. This latter has four movements: hoist, trolley, rotate, and travel. With this type of crane it is possible to get a high lift at a large radius, as well as at a small radius.

The half-gantry and gantry cranes are usually used for handling plates. The half-gantry has one leg on the ground and the other end is carried on a rail attached to the side of a building. A gantry crane is one that has the hoist mounted on a trolley carriage the same as a travelling bridge crane, but it differs from the latter in that it has two legs. Some of these gantry cranes have a cantilever boom such as shown in Fig. 8.

The travelling bridge crane such as is common in manufacturing plants is not used to great extent in shipyards, but occasionally they are made use of over the shipways as shown in Fig. 7.

Both direct-current and alternating-current power have been used successfully on shipyard cranes. With direct current, dynamic braking control is usually employed on the hoist. This gives power hoisting and partial power and dynamic braking in the lowering direction. Reversible control is used on the other motions of the crane; and for revolving cranes, such as shown in Figs. 1, 2, and 4, magnetic control with automatic acceleration should be used for revolving or slewing, as this motion is practically all acceleration. The travel motion of revolving cranes is equipped with a control to give one or more creeping speed points. In order to stop the crane without undue shocks, it is brought to a low speed by the creeping speed points and when power is shut off the brake sets and brings the crane to a stop. Creeping speed points give dynamic braking when the motor or motors are overhauled by the crane, thereby providing a means for holding the speed to a safe value when travelling with a high wind.

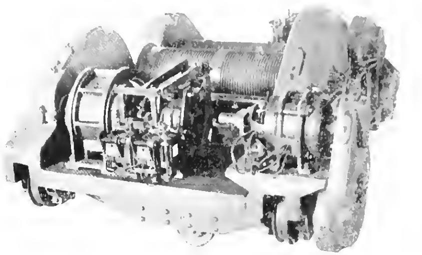


Fig. 11. Trolley Carriage with Alternating-current Crane Motors and Solenoid Load Brake Mounted on the Hoist Motor

When alternating-current motors are used, reversible control equipments are employed on all motors. If the crane is of the revolving type as shown in Figs. 1, 2, and 4, magnetic control with automatic current-limit acceleration should be used for revolving or slewing. If the operator does not travel with the hoisting machinery and an automatic mechanical load brake is not used, a solenoid load brake should be included as shown in Fig. 11. For the bridge motion, multiple magnet brakes should be used in order to bring the crane to a stop gradually. A multiple magnet brake is one that gives two or more degrees of braking corresponding to the number of solenoids used. The control would be so arranged that the first point picks up one solenoid and the second point picks up the other solenoid (assuming two degrees of braking) and at the same time energizes the motor. In stopping, power is shut off the motor and one solenoid is released, thus giving a certain degree of braking which retards the crane, and when a low speed obtains the controller is turned to the "off" position and the other solenoid is released and full braking torque is applied which brings the crane to a complete stop.

Marine Terminals

By J. A. Jackson

Power and Mining Engineering Department, General Electric Company

The cost of exports and imports is greatly increased and the time of delivery much delayed by antiquated methods of transference at the junction of the land and sea common carriers. The following article explains the shortcomings of the system in vogue and lists the design factors which must be considered in order to produce the quick turn around essential to the economic efficiency of marine terminals. It then discusses the matter of power supply and the general application of the necessary freight handling machinery.—Editor.

"Marine Terminal" is a broad term which covers piers, wharves or quays, together with the necessary supporting warehouses and other facilities such as machinery, trackage, etc. Such terminals form an essential link in the system necessary for handling the commerce of the world, and yet, until very recently, their design and operation has perhaps received less scientific thought and study than any other link in the system.

The over-night growth of our merchant marine to be the second largest in the world, the breaking down of the railroad system of this country, and the enormous tonnage of our commerce has thrown upon marine terminals a tremendous burden. While the peak of this burden no doubt passed temporarily with the ending of the war, a steady volume of commerce equal to the war peak volume will unquestionably result in the near future due to the intense industrial activity which will result from the competition between the leading nations of the world for commercial supremacy. The attainment of this commercial supremacy will depend largely on efficiency of production, using production in a broad sense to cover not only manufacture but transportation.

Of all the links in the entire system of production from the raw material to the delivery of the finished product, terminals have probably the lowest efficiency. When one considers the immense amount of study which has been given to increasing the efficiency of our industries and to that part of our transportation system other than terminals, it is nothing short of astounding that terminals have been so neglected. The low efficiency of terminals is due partly to the poor design of practically all except those built during and since the war and partly to the extensive use of manual labor instead of machinery.

In the design of marine terminals, there are certain fundamentals which must be considered: First, the ratio of terminal shed cubic capacity to the tonnage of the boats which can dock alongside at any one time, making due allowance for aisle space and the height to which cargo can be safely and economically piled. Second, the proximity of supporting warehouses and the ratio of their cubic capacity to the yearly tonnage through the terminal, making due allowance for the character of the freight to be handled and the average time it will be in storage. Third, the type and quantity of mechanical handling equipment which can be economically used. Fourth, the design and arrangement of suitable lighting. Fifth, the assurance of a continuous power supply. Sixth, the location and arrangement of railroad connections. Seventh, the arrangement and size of driveways and tail board space for motor trucks and drays. Eighth, the width of slips (water space between piers).

The economic efficiency of a terminal should, and undoubtedly will in the future, be measured by its ability to show a quick turn around for both boats and cars entering it. Boats and cars are earning dividends only when moving and the charges against them while stationary run into enormous figures. The standby charges of a 10,000-ton boat will run from $4000 to as much as $5000 in some cases for each day in port. Furthermore it can be shown that the equivalent of over 100,000 cars can be added to our railroads if only one hour out of each present idle car day can be saved for each freight car in the United States. These two facts are pointed out simply to emphasize the importance of giving serious consideration to all points in the design and operation of marine terminals.

Since it is out of the question in a brief article of this kind to cover fully the design and operation of a terminal, especial attention will be given only to the power supply and the application of power to machinery and lighting. Connection to a reliable central station supplying electric power is without doubt the most desirable and economical power supply. Marine terminals may become sufficiently large in the future to justify their own generating stations; in fact, one is now being laid out in New York which will probably follow this plan, using alternating-current turbine-generator units and synchronous converter substations to supply direct-current power where required. It will be interesting to see what the load-factor will be on this station when operation begins, and also to see whether the generating station has sufficient advantages over central-station power to justify its existence for this class of service.

If the size of a terminal seems to justify a generating station of its own, the questions of coal supply, ash disposal, boiler feed water, and condensing water must be given careful study and the cost per kilowatt-hour should be accurately worked out to obtain a fair comparison between a generating plant and the purchase of power from a central station. This will involve a study of the required initial investment, depreciation, operating costs, load-factor, peak loads, etc., and it is predicted that in very few cases will such a study show a generating station to be more economical than central-station power, principally on account of the load-factor. If central-station power is used, precautions should be taken to insure a continuous supply by having two or more independent feeder cables. A failure of power for a short time entails too great a loss to take any chance of this kind. Suitable transformer or synchronous converter substations, or both, will be necessary and their location must be carefully considered with the view of keeping the cost of distribution copper to a low figure and to minimize the fire hazard. Spare units of all kinds should be provided to insure against a power failure.

With either alternating or direct current, 220 to 250 volts is the most appropriate voltage for power supply with a three-wire system giving 110 to 125 volts for lighting. Lower voltages run the copper investment into large figures while higher voltages, such as 440 or 550, lead into insulation troubles on account of the damp salty atmospheric conditions around the water front.

Alternating current is admirably adapted for lighting and for continuous running power equipment such as conveyors and pumps, and it can be used quite successfully for cranes, winches, and elevators. Where these latter machines are installed in large enough numbers to get a good load-factor on a converter substation, it is desirable to use direct current for them as the operating characteristics of a direct-current motor are somewhat superior to those of an alternating-current motor for these machines. If storage battery equipment such as tractors and industrial trucks are used, direct current becomes absolutely necessary and converting apparatus of some type with suitable switchboards for charging batteries must be installed.

The power requirements for a terminal are going to depend largely on the attitude of the owners towards the introduction of labor saving machinery and also to the ability of the operating force to make full use of such machinery as is supplied to them.

Fig. 1. Airplane View of a Modern Marine Terminal—The Boston Quartermasters' Terminal—showing the two-story pier sheds served by gantry cranes and the eight-story supporting warehouse in the rear. The powerhouse for the terminal is also shown. It provides for heating the buildings and also contains substation equipment for converting the power obtained from the Edison Electric Illuminating Company

The majority of the marine terminals now in operation are narrow one-story pier sheds on which no machinery is used or can well be used for want of space, so that their power requirements are limited to lighting. Such terminals are not efficient and never can be, hence they cannot be referred to as a guide for determining the power requirements per ton handled. In fact, there are scarcely any completely equipped efficient terminals which have operated long enough at anywhere near capacity to get reliable data either on power requirements or on the type and quantity of machinery to install. For the present then, theoretical calculations must be relied upon for such information.

In the past, the ships' deck winches have been relied upon entirely for loading and unloading and all handling in the pier shed has been done with hand trucks. In warehouses, a few low-speed freight elevators have been used and in some cases whip hoists have been employed for hoisting freight up the outside of the building. The labor situation and the demand of the public for higher efficiency and lower costs is compelling a change. Cranes of various types and portable electric winches are taking the place of the ships' winches for hoisting cargo in and out of the hatches. In some cases where conditions permit, conveyors are handling cargo in almost a continuous stream between piles in the pier shed and the deck of the ship, leaving only the hoisting from the hold to the deck to be performed by cranes and winches. With commodities such as bananas and bagged goods, special conveyors are designed to deliver or receive the goods in the hold of the vessel itself, thereby transferring the material from the hold to a point well within the pier shed without manual labor or any break in continuity of movement.

Inside the pier shed and the warehouse and on open sections of the terminal there is a big field for power driven machinery to supersede the hand truck and manual labor for the horizontal movement of cargo. Extreme flexibility is essential as high efficiency demands continuous transfer without rehandling between the ship's side and the pile or vice versa. As the pile may be located at any point in the pier shed or even on the top floor of an adjoining warehouse, it is plain that fixed machinery such as conveyors or machinery on tracks does not have the required flexibility. This leaves the field open to storage battery industrial trucks and tractors with trailers, as, with suitable elevators, they can reach any point in a terminal. Their value in this field is being rapidly appreciated and many terminals now have a full or partial equipment of them. Suitable battery charging stations under the supervision of a competent storage battery man are essential for the successful operation of tractors and trucks. If alternating current only is available, converting apparatus must be used for obtaining the direct current necessary for battery charging.

At terminals where ships with side ports dock, tractors and trailers or industrial trucks will frequently take freight onto the boat, delivering it direct to the stowers, thereby avoiding any rehandling between the boat and the pile. Where tidal conditions make steep grades between the pier deck and the side port, power ramps or conveyors hinged at the shore end are used to assist trucks and tractors up and down the incline.

In terminals where the design or operation is such as to require all material to be stored in the pier shed, such as in piers not supported by warehouses, the monorail crane on an adjustable loop track may be profitably employed to handle cargo between the hold and the pile without a rehandling.

The growing use of two or more story pier sheds with multi-storied warehouses in close proximity makes the use of elevators imperative and their platform area, capacity, speed, location, method of control, etc., all require considerable study to assure high all-around operating efficiency of the terminal. The terminal elevator of the future must be capable of lifting a loaded $7\frac{1}{2}$-ton auto truck to the second story of the pier shed or a tractor with a train of four or five loaded trailers to the top story of a warehouse. The number and location of elevators must be such as to avoid circuitous routing and to assure little or no waiting. For any elevator speeds which are necessary in this class of service, alternating current can be successfully used provided the electrical equipment is properly designed.

Piling machines of the inclined conveyor and the vertical lift type also find a place in the power equipment used in terminals. Their sphere of usefulness is more confined to the warehouse as high piling is often prohibitive on the pier on account of the number and size of consignments and the necessity for leaving "marks" visible for inspection, etc.

The selection of power-driven machinery for an entire terminal involves quite a complicated problem since the operation of the various types of units is so co-related that a shortage of any one type may prevent other types from working up to capacity. On the other hand, idle equipment earns no dividends—hence a surplus of any one type means idle capital. Sufficient machinery should be provided, however, to keep busy such manual labor as must necessarily be employed, for an idle laborer is worse than idle machinery.

The art of illuminating engineering, which has been applied so effectively and efficiently to our industries, can be applied with equal effect to terminals and certainly should be applied to the fullest extent. Ample illumination prevents loss of time by enabling stevedores to read marks and locate consignments rapidly; it reduces accidents by showing up dangerous places and conditions; it reduces theft and produces a cheerful atmosphere which is conducive to efficiency.

For good average illumination in marine terminal buildings there will be required from $^1/_4$ to $^1/_2$ watt per square foot of floor surface, figured on the basis of using modern high efficiency incandescent lamps with suitable reflectors. Arc lighting is a thing of the past for lighting of this character.

There is perhaps no one more interested in efficient terminal operation than ship owners and operators, as a quick turn around may mean the difference between dividends or a loss on their invested capital. It is to be hoped therefore that the marine fraternity as a whole will do all in its power to support a general demand on the part of the public for modern terminals efficiently operated.

Electric Motors and Control for Dry Docks

By L. F. Adams

Power and Mining Engineering Department, General Electric Company

Whether a ship be dry docked by pumping the water from around the hull, as in a basin dock, or by raising the ship above the water level, as in a floating dock or in a marine railway, the suitability of electric power for the purpose has resulted in its universal use. The following article describes the types of motors and control employed to operate the main and auxiliary pumps, the valves, and the haulage mechanisms.—Editor.

The dry docking facilities in the country have not kept pace with the construction of ships. We have built up a big merchant marine, but little has been done toward providing means for keeping this fleet in condition for service. Vessels lay in harbors for weeks awaiting their turn for necessary renovation. As a result there are a number of dry docks now either under construction or contemplated, and it is essential that they utilize modern electrical equipment.

There are three types of modern dry docks, basin or graving docks, floating docks and railway dry docks;* and one or more of each type are now under construction at various plants. The first two types require a pumping plant either on shore or on the dock itself. The third type requires a means for hoisting the cradle on which the vessel rests. In the earlier dry docks steam-driven reciprocating pumps or engines were used, but today electric motors and control are universally adopted for all types.

In the basin or graving type of dock a pumping station is essential and is usually placed a short distance inside the outer entrance. Two or more large main pumps and one or more drainage pumps of the centrifugal type driven by electric motors, with possibly a motor-driven sump pump and motor-driven valves, together with the necessary control are required. The motors for driving the main and drainage pumps in modern docks are of vertical construction and of either the slip-ring or squirrel-cage type, usually the slip-ring type for the main pumps and the squirrel-cage type for the drainage pumps. The sump pump and valve motors are invariably of the squirrel-cage type.

A caisson is needed for closing the dock entrance. Sometimes the dock is divided into two sections by a second caisson. Vertical induction motors are employed for driving the pumps and high-torque induction motors operate the valves. Large docks of this type recently completed and put in operation are the Hunter's Point Dry Dock of the Bethlehem Shipbuilding Corporation, Ltd., San Francisco; Dry Dock No. 4 at the Portsmouth, Va., Navy Yard; and the Commonwealth Dry Dock at Boston, the largest on

* For a description of Railway Dry Docks or Marine Railways see the article by C. B. Connely in this issue.

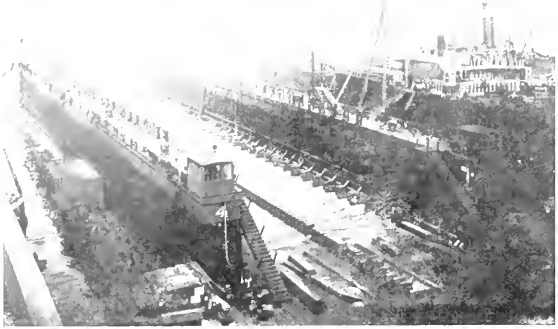


Fig. 1. Floating Dry Dock of the Bethlehem Shipbuilding Corporation, Showing Five 46-h.p. Vertical Totally Enclosed Induction Motors and Control House on Each Wing of the Dock

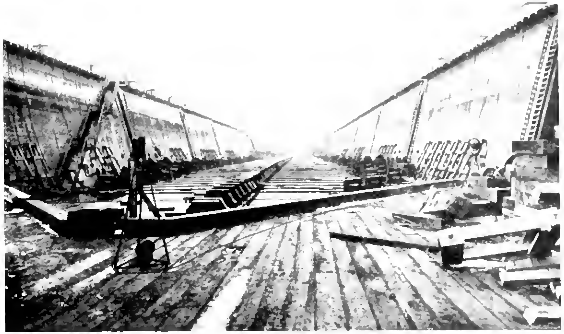


Fig. 2. All Six Sections of the 30,000-ton Floating Dry Dock of the Morse Dry Dock and Repair Company Ready to Submerge and Rise Again Holding the Ships Seen in the Distance

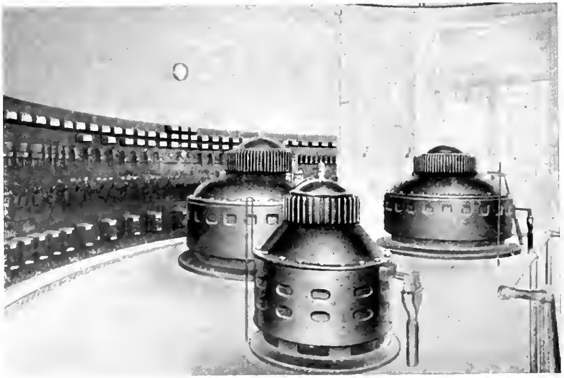


Fig. 3. Circular Pump Room of the Bethlehem Shipbuilding Plant, Containing Four 750 h.p. Main Pump Motors and Two 100-h.p. Drainage Pump Motors

Fig. 4. Interior of Caisson of the Bethlehem Shipbuilding Plant, San Francisco, Calif.

the Atlantic coast. A similar dock is under construction at the Philadelphia Navy Yard.

The wooden or steel sectional floating dry dock as compared to the basin dock is generally cheaper in first cost, usually less expensive to operate and has greater flexibility in service. The pumps are of the vertical centrifugal type, designed to operate efficiently under a variable load and located in the pontoons, one or more being required on each side of each pontoon. The pumps are driven through vertical shafting by squirrel-cage or slip-ring induction motors placed on the decks of the wings. Many of the latest docks are also equipped with motor-operated valves. This type of dock is usually built to handle 8,000 to 12,000 tons, although a few of larger capacity are in use, notably the 20,000-ton dock of the Bethlehem Shipbuilding Corporation at Sparrows Point, Md., and the 30,000-ton dock of the Morse Dry Dock and Repair Co., Brooklyn, N. Y.

As has been stated, alternating-current motors are generally used on all types of dry docks. The main pumps for basin dry docks require motors from 700 to 1300 h.p. Drainage pump motors and pump motors for the caisson for this type of dock range from 50 to 200 h.p. The thrust bearing supports not only the weight of the rotor, but also the shafting and pump impeller, and in addition takes care of the water thrust. As the motors, except those in the caisson, are placed in a well constructed station they may be designed for 2200 volts or lower. Caisson pump motors, sump pump motors, and valve motors are always wound for 220 or 440 volts.

For floating dry docks modern design tends toward a vertical direct-connected motor for each pump, the thrust bearing of the motor supporting the entire weight of the revolving parts. Motors are either of the squirrel-cage constant-speed or slip-ring varying-speed types, depending upon the method adopted for operating the dock. The capacity of the motors ranges from 20 to 125 h.p. depending on the size of the dock, the number of motors to each section, and the time allowed for raising. In some cases the vertical shafts driving the pumps are connected through bevel gears to a line shaft running along the deck of the wing. The line shaft is split near the center and is driven through spur gears by a horizontal slip-ring motor of from 125 to 200 h.p. with a pinion mounted on each end of the motor shaft. The motors are usually wound for 220 or 440 volts, although 2200 volts may be adopted on condition that provision is made for keeping the temperature of the air surrounding the motor slightly above the outside air so as to prevent condensation. Three docks using 2200-volt motors are in successful operation. Such installations require a house over each motor and this has been the usual practice even when lower voltages have been used. However, a new type of weatherproof vertical dry-dock motor designed for 220 or 440 volts has been recently developed and is placed on the wings without any other protection from the elements. A large number of such motors have been furnished for recently constructed docks.

Most of the motors for railway dry docks vary from 100 to 250 h.p. in size, depending on the capacity of the dock, and are usually wound for 220 or 440 volts, although 2200 volts should be satisfactory because the equipment is placed in a suitable house at the head of the track. On account of the large torque required, slip-ring type induction motors are always specified.

The control for dry-dock motors may be either of the hand-operated type or of the magnetic type remotely operated through control switches. For the larger motors in basin dry docks the magnetic type of control is preferred, while for the smaller motors standard hand-operated starting compensators or drum-type controllers may be used, but even here there is a decided tendency toward the magnetic type of control. On floating dry docks, modern practice demands the magnetic type of control and the placing of the control boards mounting the contactors, relays, and protective devices alongside the motor on the wings of the dock in a weather-proof box and operating through control switches placed in a house on the pier at the end of the dock. The latest type of motor operated valve employs magnetic control mounted in the valve stand and the control switches also located in the control house on the pier. The dock master directs the docking of a vessel from this point so the entire control of the dock is made most accessible by such an equipment. A manually operated controller usually meets all requirements for operating the motor for railway dry docks, except that the magnetic control is sometimes used for motors of large capacity and invariably for 2200-volt motors.

Marine Railways

By C. B. Connely

Power and Mining Engineering Department, General Electric Company

Dry docks of the railway type, commonly known as marine railways, have recently been built in capacities sufficient to accommodate all but the largest of the ships built on the wartime program of the Emergency Fleet Corp. While docks of this type, but of smaller size, have been in use for a number of years, the successful operation of the recent ones of large capacity will undoubtedly result in the installation of many more. The author describes the construction, operation and electrical equipment, and discusses the considerations involved in determining the size of the haulage motor.—Editor.

Government reports for the last fiscal year state that there are a total of 3482 American merchant ships, government and privately owned, with a total gross tonnage of 11,708,342 or an average of 3360 gross tons per boat.

The Emergency Fleet's wartime program was the following:

510 vessels less than	5000	tons dead wt.	27%
215 vessels of	5000– 5999	" " "	11%
84 " "	6000– 7499	" " "	4%
271 " "	7500– 8499	" " "	14%
644 " "	8500–10,000	" " "	34%
188 " "	10,000 and over	" " "	10%

From the foregoing it will be seen that 90 per cent of the ships built were less than 10,000 tons dead weight capacity or as will be shown later, within the capacity of modern marine railways.

For our newly acquired merchant marine to be successful and efficient, ample facilities for repairs must be provided at points well distributed along our coast line. Since a large percentage of our tonnage is in boats of 5000 tons deadweight capacity or less, and since many of our ports have channels and docks which will not accommodate larger boats, there is no necessity for these ports to provide repair facilities beyond this capacity. Furthermore, many of our smaller ports do not draw sufficient trade to justify large expenditure of capital in repair plants. To meet these conditions, the marine railway (or railway dry dock) is almost ideal. The financial outlay is relatively small, since the essential parts consist of a wheeled cradle on inclined tracks extending from the shore out into the water to the proper depth together with the necessary motive power and braking apparatus for hoisting and lowering the cradle and ship at a suitable speed.

Marine railways are of two types; viz., end haul and side haul; and may be constructed of wood, concrete, steel or composite. The modern marine railway differs from the older type in that vessels are now lifted from the water on an even keel, whereas in the older type the forward end of the vessel was carried out of the water for some distance before the keel had grounded along its entire length, thus causing undue strains in the hull.

Owing to the low initial cost and the very reasonable operating expense of marine railways, their use appeals to the ship repair company; and the experience being gained with our increased merchant marine has led to the building of marine railways considerably larger than has heretofore been thought feasible. Up until recently, a railway for a 5000-ton deadweight vessel of an actual weight approximating 3000 tons was considered as being the limit in design. In 1920, however, two railways have been completed by the Moore Shipbuilding Company having capacities for ships of 15,000 tons deadweight weighing up to 8500 long tons, and these will accommodate any of the ordinary ocean going freighters and tankers up to 500 feet in length, even with a partial cargo or a fuel supply in the bunkers. Before the construction of these two, the Moore Shipbuilding Company had in operation the then largest one in the world, having a capacity for ships weighing 5200 tons. All three docks were designed by and constructed under the supervision of Leland S. Rosener, Consulting Engineer, San Francisco.

The essential elements of these docks are long inclined tracks, sloping from the shore to deep water, a cradle traveling up and down these tracks on roller trains, on which the ship is supported, and an electric hoist located on the shore which hauls the cradle up the incline and lowers it by means of chains. Each dock consists of a cradle approximately 500 ft. long and 76 ft. wide, an incline track system upon which the cradle moves from its point of maximum submersion to a point above the high-water line, and a hauling system consisting of a set of chains operated by an electrically driven hoisting mechanism. Each of these new docks is hauled by eight chains arranged in parallel and automatically equalized. The chains are made of refined iron, hand-welded, and thoroughly proof-tested at the factory.

The hoists were built in the Moore Shipbuilding Company's shops from Mr. Rosener's design. They are driven by 500-h.p. slip-ring 450-r.p.m. motors with wound rotors controlled by liquid rheostats and magnetic control. Speed reduction from the motors to the

Fig 1 A Shore View of the *Lyman Stewart* and *Arakan* on the Moore Shipbuilding Company's Railway Dry Docks. The two concrete buildings in the foreground house the hoists for hauling in the cradles

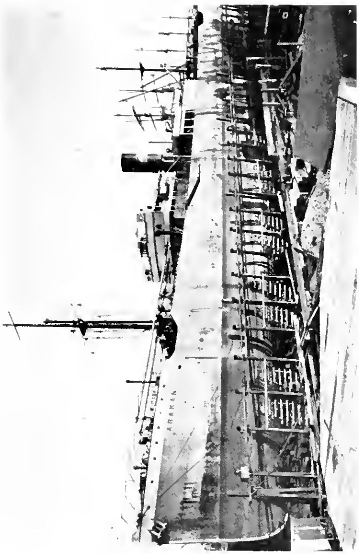


Fig. 2. The Dutch Steamer *Arakan* on Dry Dock After She Had Gone Ashore in a Storm a Few Miles North of the Entrance to the San Francisco Harbor. One of the Sprague electric capstans is shown

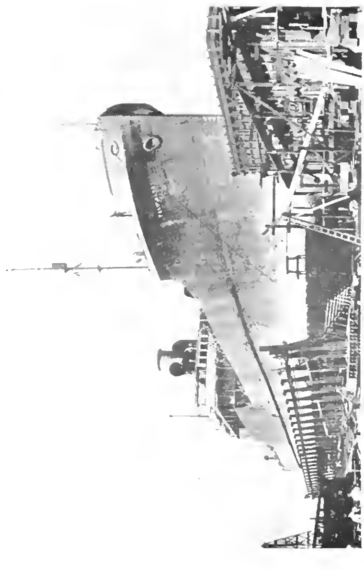


Fig 3 The Largest Concrete Ship Ever Built, the *Palo Alto*, Weighing 7115 Long Tons Without Cargo or Fuel

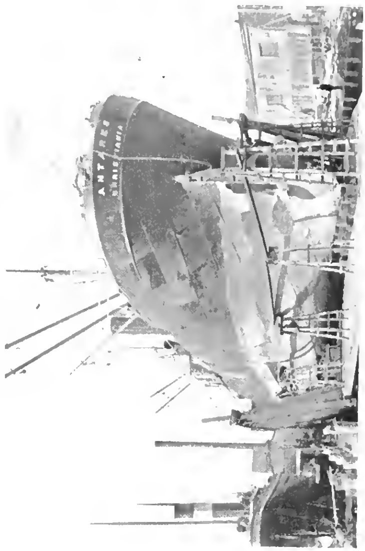


Fig 4 Steamer *Antares* on Crandall Engineering Company's Marine Railway

main-head shafts, on which the chain wild cats are mounted, is made through three sets of spur gears. All of the gears are of steel, the fast train of motor reduction gears being cut and the other slower trains being cast gears. When lowering a ship regenerative braking is used, that is the main motor being driven overspeed returns energy to the line. This practically eliminates the use of the hand-operated post brakes and the air-operated band brakes, these being used only at the instant of stopping or in an emergency. A combination clutch and gear shifting arrangement permits operating the hoists at the low speed of 16 feet per minute for large ships, or at a speed of 28 feet per minute for lighter loads.

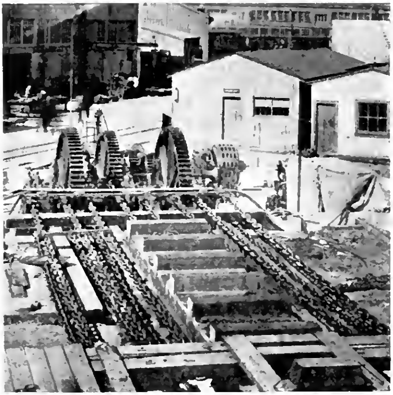


Fig. 5. A View Toward Shore from End of the Cradle, Showing the Electric Hoist and Chain Arrangement. The motor is of the slip-ring type and rated at 500 h.p. The liquid rheostat is covered by the canvas in the foreground

The length of time required for docking a ship after it is started into position averages about 40 minutes, in fact three ships on separate railways have been docked with one crew on a single tide. The heaviest ship handled to date is the concrete tanker *Palo Alto*, shown in Fig. 3, which weighs 7115 long tons. The power demand for raising this ship was from 165 to 565 h.p., the latter being required for only five minutes at the upper end of the travel.

As may be seen from the photographs, the cradles are provided with elevated frame work along both sides, the top of which is always above water. On these sides are mounted hand winches for operating the bilge blocks, and electric capstans which are used to float the ships to the proper position over the keel blocks.

A four-wire trolley system located between the two docks supplies three-phase 440-volt current for the operation of the capstans and for lighting, and also serves as a signal system between the cradle and the hoist house. This trolley system is very similar in construction to the trolley system of a crane located along the crane-way and consists of four bare wires loosely carried on insulating blocks and a collector device, which is mounted on the railway, slides along the wire.

Fig. 1, 2, 3, 6, and 7 show various vessels on dry docks of the Moore Shipbuilding Company at Oakland, Calif. Fig. 1 shows the 6055-ton steamer *Lyman Stewart* on a 7500-ton dry dock and the 5106-ton steamer *Arakan* on an 8500-ton dry dock. Fig. 4 shows the steamer *Antares* on a Crandall Engineering Company's dock and gives a good idea of the general construction from the water end.

The use of electricity as a motive power for driving a marine railway, as compared to a steam plant, is ideal for standby, and power charges are a minimum and power is always available up to maximum requirements. Repair costs are held to a minimum and the investment for electrical apparatus is nominal. The selection of the proper electrical appara-

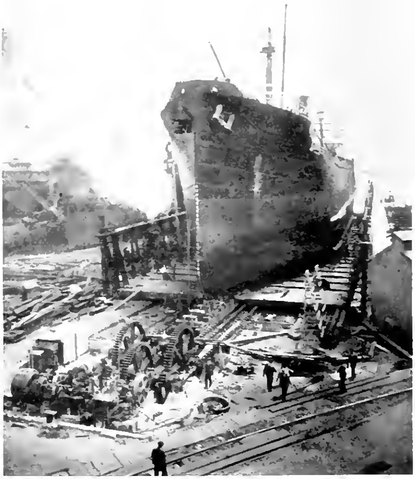


Fig 6. A View of the *Orani*, Showing Especially Well the Hoist and Chain Arrangement, as Well as the Cradle, Tracks, and Roller Trains The view was taken before the construction of the hoist house

tus involves due consideration of the work the motor is called upon to perform. Fig. 8 shows a curve of the chain load on the Crandall Engineering Company's railway dry docks, the cradle operating at high tide. It shows the percentage of cradle travel versus the percentage of total chain load and should apply on any size of railway dry dock. An analysis of the hoisting and lowering of the cradle shows that the pull curve starts at zero and gradually mounts as the vessel is drawn from the water until a maximum is reached with the vessel completely out of the water and being drawn into its final location. In lowering, the static friction has to be overcome in starting after which the motor is called upon to act as a brake. The characteristic of an induction motor (with which most railway docks are equipped) is that when driven by an overhauling load above synchronous speed the motor is turned into an inductive generator and returns power to the incoming power line, thus giving a braking effect. Inasmuch as the motor is only called upon at best to operate a very few times a day, the heating

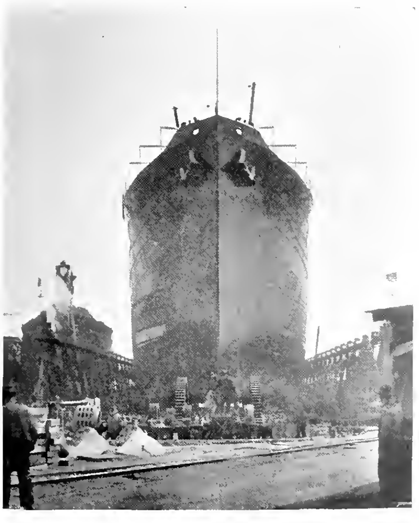


Fig. 7. A View of the Bow of the *Orani*, Showing the Electric Hoist in the Foreground

cycle of a half trip determines the heating capacity of the motor. The major portion of the heating occurs at the time of maximum pull, which is with the ship clear from the water.

Naturally, as different shipways vary as to the gradient and as to the size of the ship to be hoisted, no single motor would meet all requirements but the list of apparatus required can very well be shown by typical example. A specific cradle in hoisting a vessel weighing 3000 tons, at a torque varying from 0 to 225 h.p., required a total of 45 minutes, which

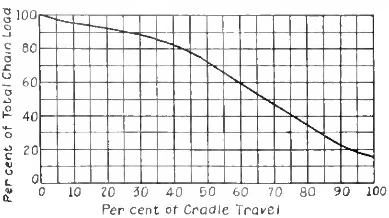


Fig. 8. Characteristic Curve of Chain Load, Cradle Operating at High Tide, on a Standard Crandall Railway Dry Dock

was equivalent in heating effect to a continuous horsepower of 155. A standard motor of 150 h.p. was therefore recommended. A further requirement was that the motor should be able to exert occasionally 250 h.p. which the 150-h.p. motor was able to do. With such a motor is needed:

(*a*) Main-line oil circuit breaker.
(*b*) Reversible drum controller.
(*c*) Reversing contactors with overload relays connected in the primary circuit; all mounted on the panel.
(*d*) A resistor for three-minute starting service.

The resistor furnished with such a control would give graduated points of starting torque of the motor to allow of low-speed manipulation. Great care has to be exercised that sufficient accelerating points are provided in the control so that excessive strains in the chain be avoided. In the very largest types of dock, such as those at the Moore Shipbuilding Company's plant, much care has to be exercised in avoiding these strains on account of their magnitude, and the consulting engineer specified a control in which liquid rheostats were used in preference to any other. While this may be necessary in the largest sizes, it is not considered necessary in sizes up to 5000 tons deadweight capacity. This listed control is fundamental and can be used either with alternating current or direct current with slight difference in detail. In alternating-current equipment, the braking when lowering the cradle loaded is done by the motor being operated slightly above synchronous speed. In direct-current equipment the braking would be obtained at any required speed by what is technically known as dynamic-braking connections.

Methods for the Production and Measurement of High Vacua

PART VII. PHYSICAL CHEMICAL METHODS (Continued)

By Saul Dushman

Research Laboratory, General Electric Company

This installment continues the discussion of physical-chemical methods of producing high vacua more especially by absorption of gases in solid substances. The composition and quantities of residual gases evolved in vacuo by glass and metals are also discussed at length. The next installment will deal with purely chemical methods of removing residual gases and also with the electrical clean-up phenomena at low pressures.—Editor.

General Remarks

From the standpoint of high vacuum technique, the phenomena included under the generic term "sorption"* are of importance in indicating what methods may be applied to clean up the residual gases in sealed-off devices. The usual gases present in such cases are hydrogen, oxygen, nitrogen, carbon monoxide, carbon dioxide, and water vapor. Inasmuch as the vessels to be exhausted ordinarily consist of glass and also have metal parts, it is furthermore of importance to consider the behavior of different kinds of glass and metals with respect to sorption and evolution of gas.

In the previous installments of this series we have already discussed the adsorption of different gases by charcoal and palladium black. In all these cases, the initially evacuated adsorbent takes up a portion of the gas with which it is in contact and the distribution of gas between the adsorbent and the gas phase depends not only upon the temperature of the former but also upon the initial total amount of gas present. Furthermore, different gases are adsorbed to a widely different extent by the same adsorbent as has already been illustrated in the case of charcoal. A similar statement holds true for the adsorption of the same gas by different adsorbents. Table XXIII taken from Freundlich[1] gives a comparison between the behavior of wood charcoal, meerschaum, and glass powder as adsorbents.

While the adsorption of gases by charcoal has been studied extensively because this substance is such a powerful adsorbent for most gases, especially at very low temperatures, many other substances have also been found to exhibit the same property. Meerschaum, powdered glass, silica, alumina, glass wool, thoria, and other substances in a finely divided state have been used as adsorbents in special cases. The gel of silicic acid has been studied[2] with respect to its adsorbing power for SO_2. Merton[3] has observed that finely divided copper, obtained by reducing a solution of a copper salt, adsorbs hydro-carbons, nitrogen, and hydrogen with great rapidity. The copper should be heated to a temperature not exceeding 250 deg. C. It gradually loses its adsorbing power with use, but Merton finds that it can be used to clean up the residual gas, after exhausting with an oil pump, to such a low pressure that the space becomes "non-conducting."

In general, adsorbed gases are re-evolved on heating the adsorbent; that is, the reaction is reversible or practically so. The sorption of oxygen by charcoal and the metals, platinum and palladium is, however, not of a similar nature. The behavior of charcoal in contact with oxygen has been studied by a number of investigators. When charcoal which has adsorbed oxygen is heated, only a

TABLE XXIII

ADSORPTION OF GASES BY DIFFERENT ADSORBENTS

Adsorbent	Gas	Vol. Adsorbed at 100 mm. Hg. and O deg. C.
Wood charcoal	CO_2	24.9 cm^3/gm.
	NH_3	95.1
	SO_2	73.6
	CH_3Cl	57.7
Meerschaum	NH_3	84.5
	SO_2	24.3
	CH_3Cl	27.1
Glass Powder	CO_2	1
	NH_3	9
	SO_2	6

* This term was introduced in Part VI of this series (General Electric Review, 1921, p. 59) as a general designation to include the various phenomena of clean-up of gases by solids.

[1] Kapillarchemie, 1909, p. 97.

[2] J. McGavack, Jr., and W. A. Patrick, J. Am. Chem. Soc. *42*, 946 (1920).

[3] J. Chem. Soc., London, *105*, 645 (1914).

portion of the gas is recovered as oxygen, the remainder is re-evolved as carbon monoxide and dioxide. The results of the most recent investigation of this subject, by H. H. Lowry and G. A. Hulett,[4] lead to the conclusion that while some of the oxygen is adsorbed on the surface of the charcoal and may be recovered by heating, the rest is held by the charcoal as a surface compound or compounds, which are stable at ordinary temperatures but which break down to CO and CO_2 at 200 deg. C. and above.

Platinum black (prepared in a manner similar to that used for palladium black) can take up more than 800 times its volume of oxygen. This oxygen is removed with great difficulty, showing that the adsorption is not a reversible phenomenon. Here again, the conclusion has been drawn that PtO is formed on the surface.[5] We shall show in a subsequent connection that in reality these adsorption phenomena are probably not essentially different from the ordinary reversible cases of adsorption.

Sorption of Gases by Metals

A survey of the results obtained by a large number of investigators shows that the sorption phenomena of gases by metals are of quite a complex nature.[6] Not only do we have cases of true adsorption, but also cases in which the gases are dissolved in the metals and behave in every way like solutions, and still other cases in which, undoubtedly, stable chemical compounds are formed either on the surface or throughout the body of the metal, and in some cases we do not yet understand the exact mechanism of the reaction. As will be pointed out in the discussion of theories of adsorption, we are dealing in such cases with phenomena which are in the "No-man's" land that exists between so-called physical and chemical reactions. It has therefore been considered best to discuss in this section all those cases in which there is an absorption of gases by solids. The behavior of hydrogen with respect to different metals illustrates all these cases very well and is of special interest from the point of view of vacuum investigations.

The sorption of hydrogen by palladium black has been discussed in a previous section.[7] At low temperatures the evidence points to the conclusion that we are dealing with a case of adsorption or surface condensation. On the other hand, there is also very good proof that, at higher temperatures at least, hydrogen dissolves in palladium in the atomic condition. The same conclusions hold for hydrogen and platinum. The latter, in the condition of platinum black, is able to take up about 100 times its volume of the gas.[8] As a clean-up agent for residual gas in vacuum devices, platinum black is less efficient than palladium black.

The behavior of hydrogen in contact with tantalum is similar in certain respects to the foregoing phenomena. Pirani[9] has observed that this metal when heated in hydrogen can occlude about 740 times its volume of the gas. On subsequent heating in a vacuum about 550 volumes are given off, while the rest of the gas is removed only at the melting point of the metal. The occluded hydrogen makes a tantalum filament quite brittle and the electrical resistance is increased considerably.

A more careful investigation of the sorption of hydrogen by tantalum was carried out by A. Sieverts and E. Bergner.[10] They observed that the amount of gas taken up by the metal decreases with increase in temperature (as in the case of hydrogen and palladium), and that a wire heated to 1200 deg. C. in vacuo absorbs hydrogen slowly at temperatures above 500 deg. However, once the wire is saturated with gas at the higher temperatures, it absorbs very much more easily at lower temperatures. At ordinary pressures, the amount of gas taken up is given by the relation

$$v = k\, m \sqrt{P}$$

where m = weight of tantalum

p = pressure of hydrogen.

Thus, as in the case of palladium, we must conclude that the hydrogen in the metal is in the atomic condition. The solubilities for different temperatures are given in Table XXIV.

TABLE XXIV

WEIGHT OF H_2 IN mg. DISSOLVED BY 100 g. TANTALUM AT 760 mm.

t deg. C.	mg.	t deg. C.	mg.
100	400	630	51.2
183	377	730	33.4
263	327	830	20.3
314	297	930	14.9
474	157	1030	11.9
530	107	1130	9.6
		1230	8.0

[4] J. Am. Chem. Soc. *42*, 1408 (1920). This paper gives a large number of references to previous literature on this subject.

[5] Engler and Woehler. Zeits. f. anorg. Chem. *29*, 1 (1902). Mond, Ramsay, and Shields, Zeits f. physikal. Chem. *25*, 657 (1898).

[6] For a general summary of the literature, see Trans. Faraday Soc. *14*, 173, 232 (1919).

[7] See references in the previous installment of this series. GENERAL ELECTRIC REVIEW, *24*, 66, Jan., 1921.

[8] For literature see Bancroft, Jour. Franklin Inst., *185*, 29 (1918).

[9] Zeits. f. Elektrochem. *11*, 555 (1905).

[10] Ber. d. deutsch. Chem. Ges. *44*, 2394 (1911).

At very low pressures the solubility is less than that calculated by the foregoing relation.

The same investigators also observed that hydrogen is absorbed by tungsten to a very negligible extent.

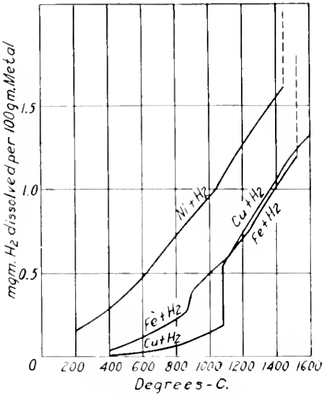


Fig. 61. Solubility of Hydrogen in Copper, Iron and Nickel

In the case of the metals, copper, iron, and nickel, the careful investigations of A. Sieverts and his associates[11] have shown that the amount of hydrogen dissolved at any given temperature varies with the pressure according to the relation

$$V = k\sqrt{P}$$

which indicates that the hydrogen is present in solution in the atomic condition. Furthermore the amount of gas taken up depends only upon the mass of the metal and not its area (as distinguished from adsorption). Also the solubility *increases* with the temperature, whereas in all cases of adsorption the amount of gas taken up decreases with increase in temperature. Fig. 61 gives for comparison the solubilities of hydrogen in each of the above metals. It will be observed that nickel is capable of dissolving appreciable amounts of the gas at higher temperatures. At the melting point, the solubility increases abruptly, as shown by the vertical dotted lines on the curves for nickel and iron, and under these conditions the former is capable of dissolving 12 times its volume of hydrogen. If the metal saturated with gas at a higher temperature is cooled very rapidly, amounts are retained which are much larger than those corresponding to equilibrium at the lower temperature. These observations are of great importance as a guide to the composition of the gases which may be evolved from metal parts used in vacuum apparatus.

The equilibrium between metal and gas is attained at a slower rate, the lower the temperature. Hence, it is necessary to heat metals in a vacuum to as high a temperature as they can stand in order to free them thoroughly of dissolved gases.

The metals of the alkali and alkaline earth group combine chemically with hydrogen to form hydrides.[12] Sodium absorbs hydrogen at temperatures above 300 deg. C. and forms the compound Na_2H. Similarly, metallic calcium combines rapidly with hydrogen at a dull red heat to form CaH_2.

The dissociation pressures of Na_2H and K_2H have been measured by F. G. Keyes.[13] Table XXV gives a few of the data obtained at higher pressures. Extrapolating from these we obtain for the dissociation pressure at lower temperatures the following values:

t deg. C.	Press. in mm.
100	7.76×10^{-6}
27	6.84×10^{-10}

That is, potassium ought to clean up hydrogen to a residual equilibrium pressure of less than 10^{-6} bar. The dissociation pressure of CaH_2 and the other hydrides of the alkaline earth group have not been determined.

TABLE XXV

DISSOCIATION PRESSURES IN mm. Hg OF POTASSIUM AND SODIUM HYDRIDES

t deg. C	K_2H	Na_2H
290		5.01
300	7.3	8.02
320	17.62	18.62
340	39.8	41.98
360	85.9	90.66
380	177.0	181.97
400	259.74	354.8

Similarly some of the rare earth elements, like lanthanum and cerium absorb hydrogen very rapidly at a temperature of about 250 deg. C. While Moissan and others claim

[11] Zeits. f. physikal Chem. 77, 591 (1911).

[12] For a general survey of the literature on the subject of hydrogen sorption by metals, refer to the paper by Donald P. Smith, "The Occlusion of Hydrogen by the Metallic Elements and Its Relation to Magnetic Properties," Journ. Physical Chem., 23, 186 (1919).

[13] J. Am. Chem. Soc. 34, 779 (1913).

the existence of compounds like LaH_3, and CeH_3, other investigators believe that we have in these cases solid solutions of hydrogen in the metals. Smith[14] classifies the combinations between hydrogen and metals into three classes:

Compounds Class 1. Hydrogen acts as a base, e.g., H_3Sb, H_3As, etc.

Compounds Class 2. Hydrogen acts as an acid, e.g., CaH_2, NaH, etc.

Class 3. Sorption compounds, e.g., palladium hydride, solutions of hydrogen in copper, etc.

With regard to a number of metals, the exact nature of the reaction with hydrogen seems very doubtful. Of the metals of the rare earth group, thorium, neodymium, praesodymium, and samarium appear to absorb measurable quantities of hydrogen, and Smith assigns these to Class 3, while other investigators assume the actual formation of hydrides. Uranium absorbs hydrogen to a slight extent, while tungsten, molybdenum, and iridium absorb little or none at all.

The writer had occasion some time ago to try some experiments on the adsorption of hydrogen by films of tungsten and iron deposited in vacuo on glass. In neither case could any clean up of hydrogen be determined. On the other hand, Heald[15] has observed that films obtained by cathodic spluttering (with high voltage) of cadmium, silver, and steel showed marked sorption of hydrogen.

On the whole, it can be stated in the light of the present information that while a number of metals take up hydrogen to a larger or smaller extent, palladium and platinum black are the only metals which are known with certainty to clean up sufficient gas to make them of value in vacuum work.

Still less is known of the behavior of other gases with respect to metals. We know that some metals, like those of the alkali and alkaline earth group, also thorium, form nitrides on heating them in contact with nitrogen, but there are very few published data on which to base any conclusion as to whether such reactions can be used in cleaning up nitrogen gas in vacuum work.

An interesting method for removing residual gases based on the reaction between these gases and thorium (or zirconium) at higher temperatures has been suggested by Dr. W. D. Coolidge.[16] "The use of the metals, calcium, magnesium, sodium, and potassium," he states, "has been suggested for the chemical removal of (residual) gases. However, the high vapor pressures of these metals offers a serious drawback to their use for all purposes and particularly for certain types of electrical apparatus, having a very high vacuum. However, the metals of the rare earth group, having a low vapor pressure, particularly thorium and zirconium, are peculiarly well suited for the removal of gases capable of chemical combination, such as oxygen, nitrogen, hydrogen, water vapor, the oxides of carbon, and the like. These metals form by combination with these gases chemically stable compounds of low vapor pressure."

Coolidge uses the metal in the form of a very fine powder. After having first exhausted the tube or bulb in the usual manner (and after all metal parts have been heated to a high temperature) dry air or nitrogen is admitted and powder introduced from a side tube. The bulb is then re-evacuated, sealed off the pump, and the glass heated at the point where the powder is situated. "The metal will be observed to glow as a reaction takes place and the result is a vacuum so high that no gas ionization effects can be observed when an electron current is transmitted" (as in a hot cathode device).

In a similar manner, Mr. H. Huthsteiner and the writer have observed that a clean copper filament treated in oxygen at low pressure will clean up the gas very rapidly and in large amounts. Apparently the oxygen is able to diffuse into the metal and thus converts it gradually into Cu_2O. On the other hand, some recent experiments by Mr. C. A. Kidner and the writer have shown that a freshly formed calcium film obtained by volatilizing the metal in vacuo does not absorb either oxygen or hydrogen, reactions which one would naturally assume ought to occur very rapidly.

The investigations of Langmuir on the clean up of gases by *volatilizing* tungsten and molybdenum filaments and of Soddy on the clean up of gases by volatilizing calcium (barium, or strontium) have yielded important results. In view, however, of the radically different nature of the reactions studied, the discussion of these must be deferred to a subsequent section.

Adsorption of Water Vapor

The problem of completely removing absorbed or dissolved water vapor from the walls of glass vessels is one of the most

[14]Journ. Physical Chem. *23*, 186 (1919).
[15]Phys. Rev. *24*, 269 (1907).
[16]Patent No. 1, 323, 836, Dec. 2, 1919.

important in vacuum work. The adsorption of water vapor by glass surfaces has therefore been studied by a large number of investigators. Closely allied with this is the problem as to the amounts of water vapor and other gases which are evolved from glass vessels under definite temperature conditions.

In one of the first investigations on this subject,[17] Bunsen observed that even at very high temperatures (500 deg. C.) silicates (chemically analogous to glass) retain appreciable amounts of water vapor. The total amount of water liberated from 2.11 sq. meters of glass surface which had previously been dried thoroughly at 20 deg. C. was 22.3 mgm. "Warburg and Ihmori[18] found that measurable amounts of water vapor were condensed upon the surface of freshly blown glass bulbs and of bulbs which had not been thoroughly washed. After washing or boiling these glass surfaces and then thoroughly drying, no adsorption of water vapor could be detected."[19] L. J. Briggs measured the sorption of water vapor by quartz powder. Fifty grams were used having a superficial area of 2.0 sq. meters. The amounts taken up at different pressures of water vapor at 30 deg. C, were as follows:

VAPOR Press. mm. Hg	WATER ADSORBED* mgm.
26.1	9.0
19.6	4.6
0.2	0.5
10.7	2.9
31.4	26.7

*Average of two or more experiments.

The last two values were obtained with samples which had previously been dried to constant weight at 110 deg. C.

The sorption of water vapor by charcoal has recently been investigated by H. H. Lowry and G. A. Hulett.[20] At a pressure of 23.4 mm. and 29.9 deg. C. as much as 783.1 mgm. of water were taken up per gm. of charcoal (estimated area of surface, 300 sq. meters), corresponding to 2.6 mgm. per sq. meter. They conclude that "water vapor is not adsorbed, but is held by capillary action."

[17] Wied. Ann. *20*, 545 (1883); *24*, 321 (1885).
[18] Wied. Ann. *27*, 481 (1886).
[19] Quoted from the paper by F. J. Briggs, Journ. Physical Chem. *9*, 617 (1905), on the "Adsorption of Water Vapor by Quartz."
[20] J. Am. Chem. Soc. *42*, 1402 (1920).
[21] Proc. Amsterdam Acad. *15*, 445 (1912). The abstract is quoted from Langmuir's paper. J. Am. Chem. Soc. *38*, 2283, (1916).
[22] Journ. Franklin Inst. *185*, 29 (1918).
[23] Wied. Ann *31*, 1006 (1887).

The sorption of water vapor by pulverized synthetic quartz and anorthite has been studied by J. R. Katz.[21] "The amount of water taken up reaches a fairly definite limit when the vapor pressure of the water is about 0.7 of the saturated vapor. The quantities of water adsorbed per sq. cm. of surface under these conditions were 1.3×10^{-6} gm. for quartz and 6.2×10^{-6} gm. for anorthite. These correspond to layers of water 13 and 204 molecules deep, respectively."

The result obtained by Briggs for the amount taken up by quartz at 31.4 mm. pressure corresponds to a film 2.66×10^{-6} cm. thick or about 50 molecules deep.

Similar results have been obtained, as will be mentioned below, by Langmuir in studying the gases evolved from glass bulbs. There is no doubt, however, that in all those cases, where apparently the layer of adsorbed gas is more than one or two molecules in thickness, we are not dealing with a true adsorption phenomenon. According to Langmuir, the sorption by glass is to be regarded as a process of solution of the water in the glass, in much the same manner as we know is the case in the absorption of moisture by sodium silicate and gels. It is also quite possible that in the case of powders the moisture may be actually condensed as a liquid in fine capillary spaces between the grains. Bancroft[22] mentions a number of cases in which very fine powders apparently have appreciable films of air or other gases surrounding each small particle. Thus a liter of carbon black may contain 2.5 liters of air, and it has been observed that "a rock powder which would pass through a 200-mesh sieve surged like a liquid."

The presence of such relatively large amounts of water vapor on glass surfaces and even metal surfaces (as observed by Ihmori[23]) means, however, that in experimenting at very low pressures special care must be taken to remove the water vapor by heating all parts to high temperatures with simultaneous absorption of the vapor in a liquid air trap or P_2O_5 tube.

Gases and Vapors Evolved from Glass and Metals at Very Low Pressures

While the study of sorption phenomena is of interest from the point of view of clean-up methods, the problem as to the nature and amounts of residual gases evolved in vacuum devices from the glass walls and metal parts is also of extreme importance in vacuum technique.

The evolution of gas from the walls of bulbs such as are used for incandescent lamps has been investigated by Dr. I. Langmuir.[24] "On heating bulbs of 40-watt lamps for three hours to a temperature of 200 deg. C., after having dried out the bulbs at room temperature for 24 hours by exposure in a good vacuum to a tube immersed in liquid air, the following average quantities of gas were given off:

200 cu. mm. water vapor
5 cu. mm. carbon dioxide
2 cu. mm. nitrogen.

"These are the quantities of gas, liberated by the heating, expressed in cubic millimeters at room temperature and atmospheric pressure.

"By raising the temperature of the bulbs from 200 deg. to 350 deg. C. an additional quantity of water vapor was obtained, so that the total now became

300 cu. mm. water vapor
20 cu. mm. carbon dioxide
4 cu. mm. nitrogen.

"A subsequent heating of the bulbs to 500 deg. C. caused the total amount of gas evolved to increase to

450 cu. mm. water vapor
30 cu. mm. carbon dioxide
5 cu. mm. nitrogen.

"At each temperature the gas stopped coming off the glass after a half hour of heating, only to begin again whenever the temperature was raised to a higher value than that to which the bulb had been previously heated.

"It therefore seems that even by heating the bulb to 500 deg., not all of the water vapor can be removed, but it does seem probable that after this treatment the amount of water vapor that can come off a bulb at ordinary temperatures must be extremely small.

"The internal surface of this bulb was about 200 sq. cm. The number of molecules of gas given off per sq. cm. was thus 56×10^{15} molecules of H_2O; 37×10^{15} molecules of CO_2, and 0.6×10^{15} molecules of N_2. If we calculate the number of molecules of each of the gases necessary to cover a *sq. cm. one molecule deep* (taking the molecules to be cubical in shape) we find 1.0×10^{15} for H_2O; 0.77×10^{15} for CO_2, and 0.67×10^{15} for N_2. Thus the quantities of gas obtained from this bulb correspond to: a layer of water 55 molecules deep, a layer of carbon dioxide 4.8 molecules deep and a layer of nitrogen 0.9 molecules deep."

On the other hand, Langmuir has observed[25] that glass surfaces previously heated to the softening point and then heated in vacuo gave off only 0.18 cu. mm. of water vapor (4.5×10^{15} molecules); 0.032 cu. mm. of carbon dioxide (0.81×10^{15} molecules); and 0.025 cu. mm. of nitrogen (0.63×10^{15} molecules). "These amounts correspond to the following number of layers of molecules: 4.5 for water vapor, 1.05 for carbon dioxide, and 0.9 for nitrogen. It should be noted that the amounts of carbon dioxide and nitrogen correspond to unimolecular layers of these gases."

Some very interesting experiments on determining the optimum conditions for evolution of water vapor from glass were carried out some time ago by Langmuir. It was observed that certain lamps made of sodium magnesium borosilicate glass (G-702-P) and consisting of high wattage filaments in very small bulbs blackened very rapidly if they were baked out at 550-600 deg. C. during exhaust, while lamps baked out at 400-500 deg. C. did not blacken so rapidly. The effect was ascribed to water vapor evolved from the glass during the life of the lamp and experiments were therefore undertaken to try to remedy this condition.

The following description of the experiments is taken from Langmuir's patent specifications:[26]

"Three lots of lamps were made with the same structural details and operating characteristics; the first lot was exhausted at approximately 450 deg. C., the second lot at 550 deg. C., and the third lot at 550 deg. C., at first and then at 400 deg. C. The average life of the first lot was approximately 575 hours, of the second lot 300 hours, and of the third lot over 900 hours, the conditions of operation with all three lots being the same."

Langmuir's explanation of this result is as follows: "Apparently the treatment at 400 to 500 deg. C. liberates the water vapor only from a comparatively thin surface layer of the glass. If, however, the exhaust is continued at 400 to 500 deg. C., no more water vapor will be drawn out of the deeper layers, and that which remains in the surface layer will be liberated."

[24] Trans. Am. Inst. Elec. Eng. *32*, 1921 (1913), and J. Am. Chem. Soc. *38*, 2283 (1916).
[25] J. Am. Chem Soc. *40*, 1387 (1918).
[26] Patent No. 1, 273, 629, July 23, 1918.

The main conclusion arrived at by Langmuir is that in order to remove water vapor efficiently from the walls of glass vessels, the heating during exhaust should be carried out in two or more stages of gradually decreasing temperatures. He finds that one half-hour treatment at each of the above temperature ranges is sufficient, and makes the interesting observation, which is in accord with that made by Sherwood (see below), that while the gas evolution at temperatures below 500 deg. C. practically ceases at the end of one half hour, the evolution of water vapor at higher temperatures continues indefinitely no matter how long the heating period.

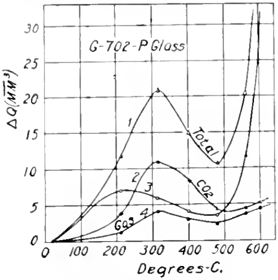


Fig. 62. Evolution of Gas from Corning G-702-P Glass

An extensive series of investigations on the gases and vapors evolved from glass has been carried out at the Westinghouse Research Laboratory by R. G. Sherwood[27] and J. E. Shrader.[28]

Sherwood measured the amounts of water vapor, carbon dioxide, and gases non-condensible in liquid air, liberated from different kinds of glass at various temperatures. Fig. 62 shows the results obtained with Corning G-702-P glass. This is a high melting-point glass which is used extensively in the manufacture of the gas-filled type of incandescent lamp. The samples of glass used in these measurements had a total area of about 350 sq. cm., and the curves show the amounts of gas liberated at different temperatures. The period of heating at each temperature was three hours. Figs. 63 and 64 show similar data with samples of soda glass, and lead glass respectively. It will be observed that in all cases the gas evolution first reaches a maximum which is at about 300 deg. C. for G-702 P, 150 deg. C. for soda glass, and 200 deg. C. for lead glass, then decreases, and again rises rapidly at a temperature which is above the softening point of the glass. Sherwood concludes that the products removed below 300 deg. C. are adsorbed gases, while at higher temperatures there is an actual decomposition of the glass itself. In other experiments, it was observed that at the higher temperatures the gas evolution continued even after the samples were heated for 24 hours and over. By previously annealing the glass at very high temperatures, the subsequent gas evolution in vacuo was decreased considerably, a result which is in accord with certain observations

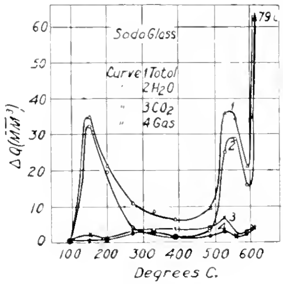


Fig. 63. Evolution of Gas from Soda Glass

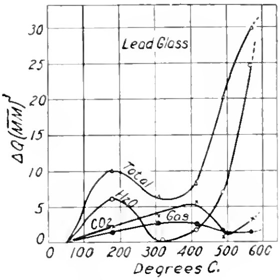


Fig. 64. Evolution of Gas from Ordinary Lead Glass

Apparently the glass actually suffers a chemical decomposition at higher temperatures.

[27] J. Am. Chem. Soc. *40*, 1645 (1918).
Phys. Rev. *12*, 448 (1918).
[28] Phys. Rev. *13*, 434 (1919).
See also abstract of a paper by Ulrey, Phys. Rev. *14*, 160 (1919), which discusses the same subject.

made by Langmuir and mentioned before. Similar results have been obtained in this laboratory by Mrs. M. Andrews and Mr. J. Pangburn in investigating the gases evolved from lamp bulbs. Analysing Sherwood's data, we find that, for instance, in the case of soda glass, the total gas evolved up to 200 deg. C. was about 50 cu. mm., or about 0 15 cu. mm. per cm.^{2}, most of which was H_2O; this would correspond to a layer of gas about four molecules deep. Sherwood concludes that the gases which are removed fairly rapidly at lower temperature are genuine adsorption products, as they correspond to quantities which are represented by a layer of gas which does not exceed one or two molecules in thickness. As the temperature of the glass is raised to the softening point, the gas evolved consists practically wholly of H_2O and undoubtedly this arises, as mentioned above, from the chemical decomposition of the glass.

Some interesting measurements were carried out by Sherwood on the adsorption of water vapor and other gases by dry surfaces of glass. Dry air could be removed very rapidly at ordinary temperature, while in the case of either moist air or air mixed with CO_2, the rate of leakage at ordinary temperature was very slow. However, on heating to a high temperature practically all this adsorbed gas could be removed in a few minutes. It is interesting to observe that in one experiment, after a pressure of about 10^{-4} mm. H_2O had been reached by exhausting, the bulb (of about 9000 cm.^{3} capacity) was sealed off and after standing ten hours the pressure rose to 0.0095 mm. owing to the gas leakage from the walls, but did not materially increase subsequently. This gas could not be condensed in liquid air, thus showing that it was adsorbed air. The writer's experience has shown that invariably there is a slight increase in pressure after sealing off the pump. Part of this increase is due to gases adsorbed on the glass near the constriction which is heated to a high temperature during sealing off, and a portion is due to gradual leakage from the walls. Even with the utmost precautions in baking out at high temperature and low exhaust pressure, there is always a slight increase in pressure in the sealed off device.[29]

In an investigation on the minimum pressure attainable with a Gaede rotary pump, the writer observed[30] that unless care was taken to heat up the tubing connecting the gage to the pump it was impossible to get below about 0.033 bars, because of the slow evolution of water vapor at ordinary temperature. When however the tubing was baked out at 330 deg. C., the pressure could be reduced to 0.0007 bars. Similar results have been reported by Shrader. The volume of the system exhausted in his experiments was about 2 liters. The effect of heat treatment on the vacuum obtainable after pumping until equilibrium was reached at that temperature is shown by the following results:

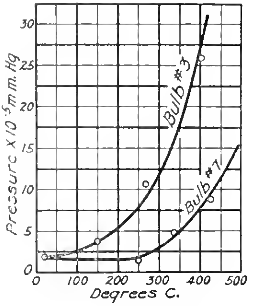


Fig. 65. Increase in Pressure in Sealed Bulb After Re-heating

Temperature	20	100	200	300	500
Press. in mm.	1×10^{-5}	1.9×10^{-6}	1.7×10^{-7}	1.2×10^{-7}	2.4×10^{-8}

Shrader also observed that not only does the vacuum in sealed vessels gradually deteriorate with time, at first rapidly and then more slowly, but also that "subsequent heating even at temperatures lower than the heat-treating temperature (on the pump) results in increase of pressure due to further liberation of gases and vapors from the glass." Fig. 65 shows the effect of heating a sealed-off system consisting of a 1500 cm.^{3} bulb and gauge of 500 cm.^{3} capacity for one hour at increasing successive temperatures. In each case the bulbs had previously been heated at 500 deg. C. on the pump.

With regard to gases evolved from metals heated in vacuo, the prevailing opinion has been that very large quantities are evolved. It has been shown however by Langmuir[31] that when care is taken to remove water vapor and carbon dioxide from the glass walls, the amount of gas actually liberated from a

[29] See Shrader, loc. cit.
[30] Phys. Rev., *5*, 212 (1915).
[31] Trans. Am. Inst. Elect. Eng. *32*, 1921 (1913). See also Journ. Am. Chem Soc. *35*, 105 (1912) for method of analysis.

tungsten filament is not more than three to ten times the volume of the wire. Most of the gas is eliminated by heating the wire to 1500 deg. C. It consists of about 70 to 80 per cent CO, the remainder being mostly H_2 and CO_2. "The total amount of gas evolved from the filament of a 40-watt lamp, if liberated in the lamp after sealing off, would produce a pressure of from 0.006 to 0.02 mm." Langmuir has also observed that the total volume of hydrogen and carbon monoxide obtained from a platinum wire heated to 350 deg. C. is only about one-tenth of the volume of the platinum.

The following data on the amounts and composition of gases evolved from different metals heated in vacuo were kindly supplied the writer by Mr. S. P. Sweetser of this laboratory. The experimental method used was that developed by Langmuir for the above mentioned measurements on tungsten and platinum. The metal in the form of a filament about 0.05 to 0.06 cm. diameter and 15 cm. long was heated to a bright red heat, and the heating continued until the rate of evolution of gas had decreased to a very low value.

Different samples of "untreated" nickel wire gave off amounts of gas varying from 5 to 15 cu. mm. of gas, consisting of about 75 to 90 per cent CO, and 20 to 10 per cent CO_2, with small amounts of H_2.

Similarly wires of monel metal, copper, and copper coated nickel-iron wire ("dumet" wire used in making lead-in-wires in lime-glass and lead-glass incandescent lamp bulbs) gave amounts of gas varying from 3 to 20 cu. mm. of gas. The composition of the gas was approximately the same as that evolved from the nickel wires.

An investigation of the composition of the gas evolved from the copper anodes used in the radiator-type of Coolidge X-ray tube gave the following average results:

CO_2	7 per cent
CO	92 per cent
N_2+H_2	1 per cent

It will be observed that in the experiments with wires, the total volume of metal used was about 0.03 cm.[3] or 30 cu. mm., and only in exceptional cases did the volume of gas evolved on heating the metal exceed the volume of the filament.

Lead-in wires and supports which cannot be heated by passing current through them or by electronic bombardment (in the case of hot cathode devices) gradually evolve gases which cause progressive deterioration of the vacuum in sealed-off vessels, so that it is necessary in such cases either to give all the metal parts that can be heated during the exhaust a much more severe heating than they will be subjected to subsequently, and thus heat the other parts by radiation or else to provide some substance which will clean up residual gases during life.

From the above date it is evident that the gases gradually evolved from imperfectly evacuated metal parts must cause fairly appreciable changes in pressure in sealed-off vessels. Thus, let us consider a 3000 cm^3 (7-inch diameter) bulb exhausted to a pressure of 0.01 bar. If this bulb contains a metal filament of the size used in the above determinations (a not unusual case), which has not been heated on the pump, the amount of gas evolved on subsequent heating, assuming it to be 10 cu. mm., will increase the pressure in the bulb to about 3.4 bars. Such a pressure would absolutely ruin the device for any electron emission phenomena, and in order to keep the pressure below 0.1 bar, the residual gas in the filament would have to be less than 0.3 cu. mm.; that is, over 97 per cent of the total gas contained in the filament would have to be eliminated on the pump.

A modification of Langmuir's method of analysis of small quantities of gas has also been described more recently in detail by H. M. Ryder.[32] The latter has determined by this method the composition of the gases eliminated from untreated, commercial copper heated in vacuo.[33] The gases evolved, in order of decreasing amounts, were CO_2 CO, H_2O and N_2. The total volume from a sample weighing 5 gm. and having a volume of 1.31 cm^3 was over 200 cu. mm. On heating to 750 deg. C. and higher, large amounts of O_2 were evolved, probably due to decomposition of Cu_2O contained in the copper. Here also, the volume of gas evolved was much less than that of the metal.

[32] J. Am. Chem. Soc. *40*, 1656 (1918).
[33] J. Franklin Inst. *187*, 508 (1919).

Studies in Lightning Protection on 4000-volt Circuits

DISCUSSION OF D. W. ROPER'S A.I.E.E. PAPER

By E. E. F. Creighton

General Engineering Laboratory, General Electric Company

In our December, 1920, issue we published a comprehensive abstract of Mr. Roper's A.I.E.E. paper and also discussions by Messrs. Steinmetz, Hayden and Goodwin. Mr. Roper presents such a wealth of information on lightning arrester performance, and he has so ably brought order out of chaos in his interpretation of the mass of data, that his paper has attracted wide attention and much discussion. Mr. Creighton has made a thorough study of the paper and his comments will be read with much interest because of his recognized ability as an investigator and designer of lightning arrester equipment.—Editor.

When we come to a mass of useful data of the magnitude of that which Mr. Roper has presented it becomes a matter for careful study and thought for days. Speaking from nearly two decades of interest in the development of protective apparatus, I know of no other example of such labor expended in gathering valuable operating data and correlating it in a form to give useful conclusions. The process of collecting these data implies, in itself, a high degree of organization in the operation of this department of the Commonwealth Edison Company.

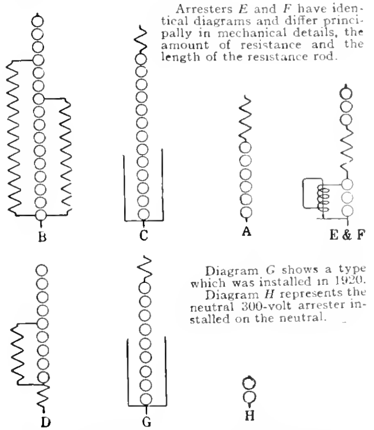


Fig. 2. (Roper's Paper) Electrical Diagrams of the Lightning Arresters Used in These Investigations

The gaps are conventional and do not show the actual shape of the gaps on all of the arresters.

There is much that could be said on many of the points brought out by the correlated data. A number of these points may be more profitably discussed by those whose experiences come nearer to distribution practice than mine. The operating engineers, even if they do not favor us with their comments, must answer to themselves the question: How do these data and results bear on my own problems of protection? Time limits my discussion to one or two phases of the subject. These phases may be found in the answer to the question: What value are these data to an engineer occupied in research and in the development of lightning arresters?

My first comments relate to the interpretation of data. Fig. 12 is a shot-gun diagram of the data in which the relation between the number of arresters per square mile as abscissas is compared to the percentage of transformer burnouts per year as ordinates. Mr. Roper has pointed out the efforts to make these data comparative. There are many factors involved, some of which are the same, on an average, in the different areas; but there are a few factors which not only vary considerably but of which the exact weight cannot be determined at the present time.

However, acceptable methods are followed which give, in the final step in Fig. 18, a direct comparison of the relative value of the arresters in providing protection. Mr. Roper has shown in Fig. 17 an intermediate step (assuming that each type of arrester gives a logarithmic curve) in comparing the density of arresters to the percentage of transformers burned out per year, and has pointed out the inconsistencies of these overlapping curves In words, the logarithmic curve says that the phenomenon varies at any point of the curve in proportion to its value at that point. This statement seems to give only an approximation of the truth.

If the matter is looked at from the standpoint of mathematical law there enters the hyperbolic law which is a first-cousin to the parabolic law. It will be seen by a statement of this parabolic law that the data have elements very closely related. In its simplest form, suppose one arrester in a given territory gives a certain number of burnouts. If two arresters are used there are two paths to ground and, neglecting all other factors except the resistance, there is half the ohmic resistance, and therefore the number of transformers burned out might be somewhat proportional to one-half. When three

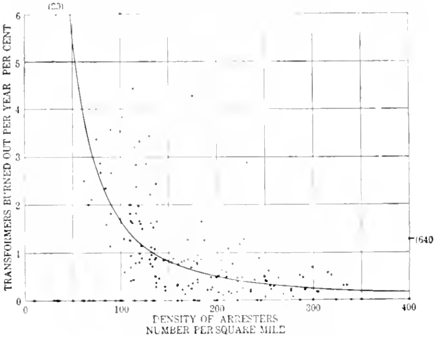


Fig. 12. (Roper's Paper) Diagram Showing for Each o 192 Sections the Average Per Cent of Transformer Burn-outs Due to Lightning for the Five-year Period Plotted Against the Density of Arresters

The curve shows for all types of arresters the final determination of the relation between density of arresters and transformer burn-outs due to lightning. The curve cannot be plotted directly from the points shown in the figure as they are not of equal weight.

arresters are used the resistance is one-third, when four are used the resistance is one fourth, etc. These values of one, one-half, one-third, one-fourth, one-fifth for the ordinates, with equal units as the abscissas, give the familiar hyperbola. It should be noted that the arresters are not concentrated at a point, but on the other hand neither is the charge that has to be dissipated by the arrester. From these general considerations I am inclined to think that both the logarithmic and the hyperbolic laws are involved and that the consideration of the combination of the two may give a consistent curve for each arrester, comparable with the others throughout the entire length of the curve. Also further study of all the elements involved in each case may give some change in the grouping of points which might clarify the shotgun diagram of Fig. 12. Mr. Roper has already done the most difficult part of the work in bringing order out of chaos. The difficulties he met can best be appreciated by those who have had to consider a mass of data which include so many variables, known and unknown.

Turning next to the question of design, the ultimate aim in all of this work is to get, as an ideal, one hundred per cent continuity of service. While it is not always economical to make such an installation, there is still the desirability of having data which will allow the operating engineer to form a judgment as to the percentage of service he may reach with definite types of arresters and methods of installing them. Furthermore, from the development standpoint it is desirable to aim at 100 per cent efficiency even if the initial financial undertaking is impracticable, because as soon as a thing becomes possible it is usual that the factors that make it possible can be adjusted to bring the cost down to a reasonable value.

The designer familiar with the characteristics of arresters involved in Mr. Roper's data is immediately given information on the character of the lightning discharges. It may not be generally known that it is possible to design arresters with as great precision as is attained by a designer of motors and the like. Laboratory methods of accomplishing this were developed years ago. It isn't a lack of knowledge of the characteristics of

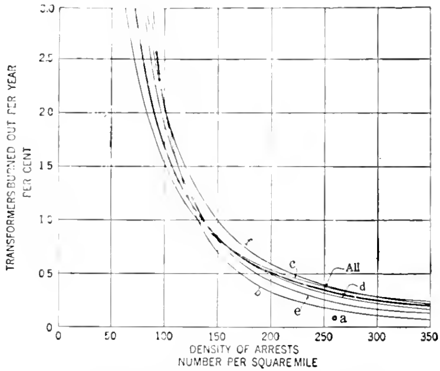


Fig. 17. (Roper's Paper) Diagram Showing the First Approximation of the Relation Between the Density of Arresters and the Percentage of Transformers Burned Out by Lightning for the Five-year Period, 1915-1919 Inclusive

arresters that we have to contend with but a lack of knowledge of the nature of the discharges that are imposed upon them. I shall make an endeavor to interpret, to the best of my ability, the bearing that Mr. Roper's data have on explaining the nature of the lightning discharges. The arrester shown in Fig. 2 over the letter *B* is the first one of the several types developed for low-voltage distribution circuits. Although expense of construction is always an important factor it was considered of minor importance in this development as compared to being able to meet the unknown conditions of lightning discharges on a distribution circuit. One known factor was that the lightning discharge is of short duration. It was not known, however, whether all lightning was of high frequency, medium frequency, or low frequency. We had no way of knowing whether it was always of steep wave front or of how slanting wave front. We could not tell whether the quantity was relatively great or small, which is only another way of stating that we did not know how many miles of line would be charged to a high potential by induction from thunder clouds.

We did know, however, that the dielectric of the transformers the arrester was designed to protect was tested at 10,000 volts for a minute between primary and secondary, and that there were liberal factors of safety of insulation between turns and between layers. This gave the criterion of spark voltage of the

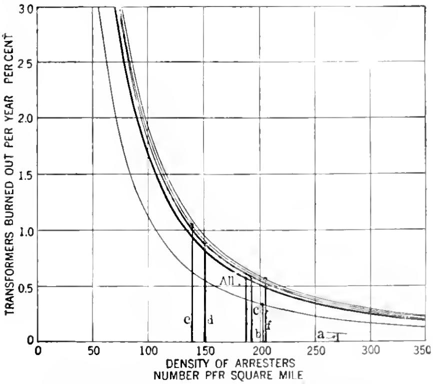


Fig. 18. (Roper's Paper) Diagram Showing the Final Determination of the Relation Between the Density of Arresters and the Percentage of Transformers Burned Out by Lightning

arrester. The spark voltage should be made less than 10,000 volts if possible. On the other hand, the spark voltage must be above the value generated by accidental arcing grounds unaccompanied by resonance because such voltages are continual and will cause the destruction of this type of arrester. As to the laboratory tests, it was required of the arrester that the equivalent sphere gap on high frequency, medium frequency, and low frequency under small and large quantities of discharge should be kept within the dielectric strength of the transformers so far as they were known by test.

To make a long story short, it resulted, in the final design of this arrester, in placing three gaps in series and arranging the electrostatic conditions between gaps such as to give a voltage breakdown of 6400 volts on 60 cycles and less voltage on high frequency. Tests were also made with single uni-directed impulses and also on direct current to make sure that no gradually accumulated charge would damage apparatus by not being able to spark over these gaps. It was necessary in this circuit to keep the series resistance very high because of the frequency of discharge and the weakness of the arc-interrupting power of three gaps. A great gain, however, was obtained by the fact that the line and lightning voltage had been led three gaps down the string of gaps. The sparks oscillating in these gaps are good conductors of electricity. The natural frequency of these sparks is of the order of a billion cycles per second. I am speaking now not of the lightning discharge but of a local discharge between the brass cylinders which make up the three gaps.

With this tremendously high frequency and consequently short time of operation, three of the series gaps having been bridged and a small discharge started to earth, the same lightning voltage may now jump the next three gaps with the same ease. There is here the evident advantage of bridging six gaps by making it in two lower voltage jumps of three gaps each. The excess voltage required to jump the second group of three gaps is sometimes as small as 200 volts, although it required 6400 volts to spark through the first three. The ohmic resistance of this rod is not fixed—it does not follow Ohm's law. The resistance decreases as the lightning voltage increases. The relation between voltage and resistance follows a logarithmic law—at 500 volts applied the resistance is of the order of 100,000 ohms.

This brings the connection of the line through six gaps to the low resistance, and lightning discharges too great for the high resistance find their way to earth through the low resistance rod (of the order of 25 ohms).

In the laboratory development, not knowing whether the quantity of electricity and the current of the lightning discharge would give an unreasonably high voltage drop across this low resistance, the assumption was made that it might, and a shunt path of nine gaps was provided in parallel with the low resistance to meet this contingency. In the first conception of this arrester three resistance paths were laid out by the inventors, but it was found unnecessary to introduce the medium value of resistance.

Here, then, was an arrester with its several lightning paths which responded in the laboratory satisfactorily to high frequency, medium frequency, low frequency, single impulse, steep wave front, slanting wave front, small quantity of electricity, and large quantity of electricity.

In designing the compression chamber arrester I had in mind a more compact form of cheaper construction, based fundamentally on the assumption that lightning discharges were of fairly high frequency and of considerable quantity of electricity. Since the compression chamber arrester, as then designed, does not give a degree of protection equal to the graded shunt arrester, we must conclude that there are either or both of the following factors in the induced lightning on distribution circuits—an occasional very heavy discharge, or an occasional single uni-directed impulse or a discharge of slanting wave front. Laboratory tests have shown that this arrester is not equal to the other in taking these discharges but that the antennae make the compression chamber arrester extremely sensitive to high frequency discharges.

The conclusions then are that occasionally there occurs extremely high voltage induced on the line involving a correspondingly high quantity of electricity and also that lightning discharges are not always at high frequency.

At the Washington meeting of the A.I.E.E. in 1914, the work of L. A. De Blois in taking oscillograms of induction from clouds showed that strokes with slanting wave fronts occur from time to time. However, it was impossible to infer from these tests that there were no high frequency oscillations superposed on these slanting wave fronts. The natural frequency of the oscillograph is only 5000 to 10,000 cycles per second and therefore the vibrator could not respond to a higher frequency in the clouds even if it existed. By inference the data that Mr. Roper presents indicate that such slanting wave fronts do exist without the presence of high frequency.

One of the characteristics of the distributed resistance arrester is its equivalent sphere gap under a discharge having a frequency of a million cycles per second. These are shown in curves in Fig. 1. The abscissas represent the direct-current voltage as measured by the sphere gap which starts the surge. The ordinates are the equivalent sphere gaps measured by the gap setting in parallel with the arrester. The curves are shown in pairs, the lower curve of each pair representing nine discharges over the sphere gap to one over the arrester, and the upper curve of each pair representing one discharge over the sphere gap to nine over the arrester. The lower pair of curves are the equivalent sphere gaps of the arrester under normal conditions of connection. The upper pair of curves are the equivalent sphere gaps of the fifteen gaps in series without the use of the resistance rods. Commenting on the normal equivalent sphere gap curves, an application of 10 kv. gives an average equivalent sphere gap of 10 kv. and the equivalent sphere gap increases gradually up to 16 kv. as the applied potential increases. In all this part of the curve the discharge passes over the six series gaps and through the low resistance but does not bridge the nine gaps in parallel with the low resistance rod. However, for an application of more

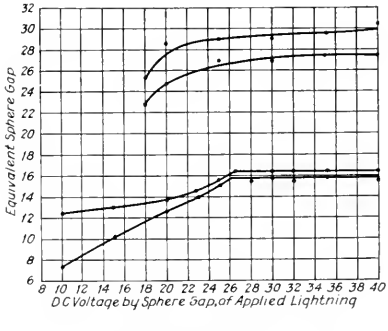


Fig. 1. Equivalent Sphere Gap of Distributed Resistance Arrester at a Frequency of One Million Cycles per Second

than 26 kv. of lightning potential the spark takes a parallel path through the nine gaps and from there on up to an unlimited high potential the equivalent sphere gap remains constant at 16 kv. Herein lies the fundamental advantage of this type of arrester, namely, the automatic limitation of the lightning voltage of the transformer terminals to a definite value which is within the dielectric strength of the modern transformers. All arresters with nine series resistances have their terminal voltage gradually increased

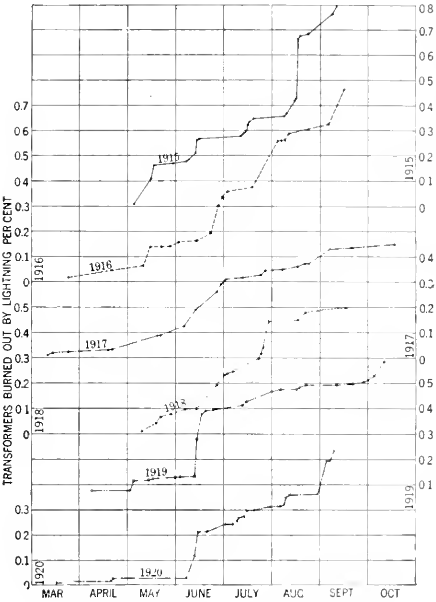


Diagram Showing the Percentage of Transformers Burned Out in Each Storm for the Years 1915-1919 Inclusive

proportionally as the severity of the lightning discharge increases.

Incidentally it should be noted that the equivalent sphere gap of this arrester is, in some cases, greater than the applied voltage. For example, at 10 kv. applied the equivalent sphere gap is 12.5 kv. when one discharge in ten is passing through the sphere gap. This value, when the resultant voltage is higher than the impressed voltage, may seem erroneous, but it is simply because the intrinsic conditions are not fully considered. The impressed voltage is direct current and is measured by a sphere gap. When this discharge is turned into an impulse the voltage may easily double. A very simple illustration of this condition is afforded by the application to an electrostatic condenser of two volts from a battery of low internal resistance which will produce momentarily four volts at the terminals of the condenser. The equivalent effect is obtained in these equivalent sphere gap tests.

The equivalent sphere gap of the gaps without resistance begins with an application of 18 kv. before they will spark. With an equivalent sphere gap of 24 kv. the curves, however, show the characteristic flattening down like the saturation curve of transformer iron. Dr. Steinmetz gave the underlying theory of the multigap arrester in a discussion in 1906 at the Milwaukee meeting of the A.I.E.E.

What is the answer and what is the next step? Naturally it is the readjustment of the compression chamber arrester to respond better to low frequency impulses and higher lightning voltage, which we are now convinced exist.

Another step is the housing of the distributed resistance arrester in a porcelain tube rather than in a wooden box.

The laboratory researches and design work on these arresters were very active 10 to 16 years ago. These arresters were sufficiently satisfactory to be lost to consideration during the great war when new problems of utmost importance were pressing for solution. I have to thank Mr. Roper for reviving my interest in this work and furnishing the incentive for further efforts toward improvement. Already a new factor has been discovered and utilized.

A Compilation of Named Effects and Laws

By L. C. KRUEGER and H. R. HOSMER

RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY

When consulting scientific literature we often see references to certain laws and effects that are usually designated by the name of the propounder or discoverer. Unless we are reading on a branch of science in which we are specially proficient, we are apt to be uncertain as to what phenomenon is indicated. In this compilation the authors have arranged in alphabetical order a convenient and useful list of the named laws and effects which are most frequently found in scientific reading.—EDITOR.

Abegg's Rule

For use in regard to a helical periodic system.

If the maximum positive valence exhibited by an element be numerically added to its maximum negative valence, there is evidently a tendency for the sum to equal 8. This tendency is exhibited especially by the elements of the 4th, 5th, 6th and 7th groups and is known as Abegg's rule.

Washburn, Prin. Phys. Chem., p. 397, 1915.

Abraham Theory

$$M = M_0 3 \frac{\left(\frac{1+B^2}{2B} \cdot \log \frac{1+B}{1-B} - 1\right)}{4B^2}$$

where

M_0 = electromagnetic mass of the negative electron for infinitely small velocities

M = transverse mass for a velocity v

$\frac{v}{V} = B$ where V is the velocity of light.

Gött. Nachr., 1902.

Ampere's Rule

To determine the direction in which the needle is deflected by a conductor carrying a current in a given direction.

Imagine yourself swimming in the wire in the direction in which the current is flowing, and facing the magnetic needle; then the north pole will be deflected toward your left hand, the south pole being deflected in the opposite direction.

Watson, Gen. Phys., 1918, p. 442.

Ampere's Theorem

The magnetic field due to an electric current flowing in any circuit is equivalent at external points to that due to a simple magnetic shell the bounding edge of which coincides with the conductor and the strength of which is equal to the strength of the current.

Nature, *105*, 199, 1920.

Apjohn's Formula

A formula connecting the pressure of the vapor in the air with the readings of the wet and dry bulb thermometers has been deduced by Dr. Apjohn.

Trans. Roy. Irish Acad., *17*, 275, 1835.
Preston, Theory of Heat, 1904, p. 447.

Arago Laws

See Fresnel.

Archimedes Principle

A body immersed in a liquid loses a part of its weight equal to the weight of the displaced liquid.

The pressure exerted by gases on bodies immersed in them is transmitted equally in all directions.

Ganot, p. 104, p. 183, 1899.

Arrhenius

Theory of electrolytic dissociation states that the molecule of an electrolyte can give rise to two or more electrically charged atoms or ions, i.e., individuals are present in greater number than would be normally expected from the mass of substance dissolved, thereby causing an abnormally great effect on the boiling points, freezing points, etc., observed in aqueous solutions of inorganic acids, bases and salts.

Lewis, Phys. Chem., 1916, I, p. 215.
Zeit. Physik. Chem., 1887.

Avogadro's Law—1811

Equal volumes of all gases at the same temperature and pressure contain the same number of molecules.

Washburn, Prin. Phys. Chem., 1915, p. 22.

Babinet's Principle

Is applied to complementary diffraction screens, by which is meant a pair of screens in which the transparent portions of one are replaced by opaque portions in the other. The diffraction patterns are the same in each case.

Wood, Phys. Op., p. 238, 1911.

Babinet's Formula for Altitude

$$\text{Altitude} = \frac{C(H_1 - H_2)}{H_1 + H_2}$$

where

$C = 32\ (500 + t_1 + t_2)$

H_1 = barometer reading at lower station

H_2 = at upper station

$t_1 + t_2$ = temperatures at stations.

C. r. 1850.
Kaye and Laby, 1916, p. 35.

Babo's Law

The addition of a non-volatile solid to a liquid in which it is soluble lowers the vapor pressure of the solvent in proportion to the amount of substance dissolved.

Findlay, "Phase Rule," 1906, p. 126.

Balmer Series of Spectral Lines

The lines of a spectrum may be expressed by a formula

$$\lambda = h \frac{m^2}{m^2 - 4} \times 10^{-8} \text{ cm.}$$

where

h = constant 3645

m = given values 3, 4, 5, 6, etc., to 11.

Wave-lengths are functions of successive whole numbers, that is, the lines of the H spectrum, for instance, form a series, and the wave-lengths of any line can be expressed as a simple function of its number in the series.

Baly, 1912, 559.
Ann. d. Phys. *25*, 80, 1885.

Barlow

The volumes of space occupied by the various atoms in a given molecule are approximately proportional to the valencies of the atoms; whenever an element exhibits more than one kind of valency the lowest is generally selected.

Roscoe and Schorlemmer (II) p. 220, 1913.

Barlow and Pope's Theory

Every crystal is a close-packed assemblage of atomic spheres which can be partitioned into small cells, all exactly similar and all marshalled in rows and columns, giving the symmetrical form to the crystal. These small cells are the chemical molecules and the atoms and molecules are assumed to be capable of a certain amount of distortion under the influence of the forces acting upon them.

Washburn, Prin. Phys. Chem., p. 68, 1915.
J. Am. Chem. Soc. *36*, 1675, 1914
J. Am. Chem. Soc. *36*, 1694, 1914.
J. Am. Chem. Soc. *36*, 1686, 1914.

Bate's Equation

$$log_{10} \left(\frac{\Lambda\, \eta}{\Lambda_0\, \eta_0}\right)^2 \frac{C}{\left(1 - \frac{\Lambda\, \eta}{\Lambda_0\, \eta_0}\right)} = k + k' \left(\frac{C \Lambda \eta}{\Lambda_0\, \eta_0}\right)^h$$

$\frac{\eta}{\eta_0}$ = ratio of viscosity of solution to that of water at the same temperature

$\frac{\Lambda \eta}{\eta_0}$ = corrected equivalent conductance

k, k', h and Λ_0 are empirical constants.

Washburn Prin. Phys. Chem. 1915, p. 216.
J. Am. Chem. Soc. *37*, 1431, 1915.

Becquerel Rays

Rays from uranium salts which have the power of discharging an electroscope whether positively or negatively charged.

Roscoe and Schorlemmer (II) p. 1413, 1913.

Beer's Law—1852

If two solutions of the same salt be made in the same solvent, one of which is, say, twice the concentration of the other, the absorption due to a given thickness of the first solution should be equal to that of twice the thickness of the second.

Pogg. Ann. *86*, 78, 1852.
Baly, 1912, p. 468.

Bélopolsky Effect

When a beam of light is reflected from a system of moving mirrors and the light is subsequently analyzed with a spectroscope, the spectrum lines are displaced by a small but easily measurable amount.

Wood, Phys. Op., 1911, p. 23.

Benedicks Effect

If a metallic conductor has one portion heated above the temperature of another portion a current of electricity may be set up and its direction will be such that by the Thomson Effect it will tend to equalize the temperature of the two portions.

Electrician *84*, 659, 1920.

Benedicks Effect

Benedicks has recently shown the existence of two effects connecting heat and electricity, one of which is claimed to be the general case, of which the Thomson Effect is a particular case. The first of these may be stated as follows: In a homogeneous metallic circuit an asymmetric distribution of temperature gives rise to an electromotive force. The second effect is a converse of the above; if through a conductor at a constant temperature containing a symmetrical constriction a current is passed, heat is absorbed on one side of the constriction and generated on the other.

Eng'g. *109*, 806, 1920.

Bernouilli Theory of Gases—1738

Gases are considered to be made up of minute, perfectly elastic particles which are ceaselessly moving about with high velocities, colliding with each other and with the walls of the containing vessel. The pressure exerted by a gas is due to the combined effect of the impacts of the moving molecules upon the walls of the containing vessel, the magnitude of the pressure being dependent upon the kinetic energy of the molecules and their number.

Getman, Theoret. Chem., 1913, p. 51.

Bernouilli Theorem

At any point in a tube, through which a liquid is flowing, the pressure plus the potential energy due to position plus the kinetic energy remains constant (friction being disregarded).

If no external forces, other than gravity, act on the unit of volume considered, then its total energy must remain constant.

Watson, Gen. Phys., p. 104, 1918.
Northrup, Laws of Phys. Science, 1917, p. 34.
Houstoun, "Introduction to Mathematical Physics," 1912, p. 40.

Berthelot's Equation

Only applicable to a pure gas.

$$PV = NRT\left[1+\frac{9}{128}\frac{p}{p_c}\frac{T_c}{T}\left(1-6\frac{T_c^2}{T^2}\right)\right]$$

p_c = critical pressure to condense gas at its critical temp.

T_c = critical temp.

This is Van der Waal's equation with value of a and b expressed in terms of critical constants of the gas.

Washburn, Prin. Phys. Chem., 1915, p. 33.

Berthelot Principle of Maximum Work

Of all possible chemical processes which can proceed without the aid of external energy, that process always takes place which is accompanied by the greatest evolution of heat. This law holds good for low temperature only and does not account for endothermic reactions.

Sackur, "Thermochemistry and Thermodynamics," 1917 p. 128.

Binet Formula

Used in testing age of individuals as to intellect.

Nature *102*, 477, 1919.

Biot and Savart

Action experienced by a pole of austral or boreal magnetism, when placed at any distance from a straight wire carrying a voltaic current, may be expressed as follows:

Draw from pole a perpendicular to the wire; the force on the pole is at right angles to this line and to the wire, and its intensity is proportional to the reciprocal of the distance.

Whittaker, "History of Theories of Aether and Electricity," 1910, p. 86.

Bjerrum Theory

Molecular heats of gases.

In the case of a monatomic gas, no energy is possessed other than that due to translational movement. As regards the rotation of the molecule as a whole, the potential energy of rotation is negligible compared with the kinetic energy. In regard to atomic vibrations the total vibrational energy is ΘRT where Θ is a function of the temperature T and of the vibration frequency v.

$$\Theta = \frac{1}{2}\frac{Bv/T}{e^{Bv/T}-1} + \frac{1}{2}\frac{Bv/2T}{e^{Bv/2T}-1}$$

Lewis, Phys. Chem. III, p. 80, 1919.
Zeit. Elektrochem. *17*, 731, 1911.
Zeit. Elektrochem. *18*, 101, 1912.

Bohr's Equation

$$V = \frac{2\,\pi^2 e^2 E^2 m\,M}{h^3\,(M+m)}\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)$$

Where V = frequency of emitted light; e and E, and m and M are the charge and mass of the electron and nucleus respectively.

Phil. Mag. *26*, 10, 1913.
Nature, *92*, 231, 1913.

Bohr's Hypothesis

Phil. Mag. *26*, 10, 1913.
Phil. Mag. *36*, 243, 1918.
Phil. Mag. *30*, 394, 1915.
Nature *92*, 231, 1913.

Boltzmann's Law

Two gases which do not react chemically are allowed to diffuse into each other, increasing in volume at the same time from V_1 to V_1+V_2 and from V_2 to V_2+V_1.

The total external work done in the mixing is

$$W = RT\left(n_1 \log_e \frac{V_1+V_2}{V_1} + n_2 \log_e \frac{V_1+V_2}{V_2}\right)$$

where

T = abs. temp.

R = gas constant

n_1 and n_2 = no. gram molecules involved

v_1 and v_2 = volume of respective gases.

Nernst, Theoret. Chem., p. 96–100, 1911.

Boltzmann-Maxwell Law

In a medium (gas) consisting of particles in motion the distribution of energy throughout a given volume will be such that, on the average, every mode of motion of its particles is equally favored, or, the kinetic energy is uniformly distributed among the degrees of freedom of the particles.

Campbell, Modern Electrical Theory, p. 81, 1913.
Northrup, Laws of Phys. Science, 1917, p. 76.

Boyle's Law—1662

The temperature being constant, the volume of a given quantity of gas varies inversely as the pressure which it bears.

PV = a constant.

This is only approximately true for actual gases and then only for low and medium pressures.

Ganot's Physics, art. 181, 1899.
Northrup, Laws of Phys. Sci., 1917, p. 72.

Boyle's Point

Each gas at a certain temperature, called Boyle's point, obeys the laws of Boyle and Avogadro exactly.

Washburn, Prin. Phys. Chem., 1915, p. 35.

Braun's Law

Piezo chemical studies.

Cohen, Zeit. phys. Chem., *93*, 385, 1919.
Cohen, J. Chem. Soc., *115*, ii 321, 1919.

Brewster's Law

If n is the refractive index of a substance and θ is the polarizing angle then $n = \tan \theta$

Watson, General Physics, 1918, p. 378.
Houstoun, "Introduction to Mathematical Physics," 1912, p. 163.

Briot's Formula

Extension of Cauchy's work.

Preston, Theory of Light, 1901, p. 487.

Brownian Movement

Seen in colloidal solutions supposed to furnish evidence of molecular motion.

Small, visible, colloidal particles are knocked about by colliding with the invisible molecules like footballs in the midst of a crowd of invisible players.

Washburn, Prin. Phys. Chem. 1915, p. 85.

When a colloidal solution is viewed through an ultra-microscope, points of light are seen due to particles which show a trembling or vibrating movement, observed first by Mr. Brown, a botanist.

Alex. Smith, p. 622, 1917.

Carnot's Cycle

Consists of four operations, performed on a working substance, which is assumed to be a perfect gas.

Partington, "Higher Mathematics for Chem. Students," 1912, p. 204.

Carnot's Theory

Work is performed in heat-engines by transporting heat from a hot body to a cold body, in a manner analogous to that in which work is obtained by allowing water to fall from a higher to a lower level.

Preston, Theory of Heat, 1904, p. 705.

Cauchy's Dispersion Formula

$$n = A + \frac{B}{\lambda_2} + \frac{C}{\lambda_4} + - - -$$

Preston, Theory of Light, 1901, p. 138
Baly, Spectroscopy, 1912, p. 74.

Charles' Law

All gases heated at constant pressure expand by an equal fraction of their volume at 0 deg. C. for equal increments of temperature.

Roscoe and Schorlemmer, Vol. 1, 1911, p. 85.

Christiansen Effect

Different colors have different indices of refraction. Glass may be invisible for certain rays which are transmitted without change, while other rays are scattered by the glass. At one temperature one color, say red, may be transmitted and at a different temperature another, say blue.

Sci. Am. Monthly, *1*, 461, 1920.

Clausius' Theorem

The change of entropy of a system subject to any reversible transformation depends only on the initial and final conditions of the system.

Preston, Theory of Heat, 1904, p. 505 and 726.
Wied. Ann. *9*, 337, 1880
Phil. Mag. June, 1880.

Corbino Effect (Hall)

When a uniform radial current flows through a circular disk of metal placed in a magnetic field normal to the plane of the disk there is produced a circular current, the density of which is inversely proportional to the radius.

Phil. Mag. *32*, 303, 1916.

Cosine Law

See Lambert's Light Law.

Coulombs' Law

The force exerted by two small charged conductors on one another is directly proportional to the product of their charges and inversely proportional to the square of the distance between the bodies.

Watson, Gen. Phys., 1918, p. 412.

Curie's Law

$$I = \frac{A}{T} H$$

where

H = magnetic field strength
I = resultant intensity of magnetization
T = abs. temp.
A = Curie's constant.

Used for paramagnetic substances.

Richardson, Electron Theory of Matter, 1914, p. 378.

Curie Point

All ferro-magnetic substances have a definite temperature of transition at which the phenomena of ferro-magnetism disappear and the substance becomes merely para-magnetic. This temperature is called "Curie Point" and is usually lower than the melting point.

Campbell, Modern Electrical Theory, 1913, p. 127.

Dalton's Law

Partial pressures.

In a mixture of gases each gas exerts the same pressure as it would exert if it were alone present in the volume occupied by the mixture.

In a mixture of gases, if the several gases have the same temperature, and if they all occupy the same volume, then the pressure exerted by the mixture will equal the sum of the pressures exerted by the gases severally.

Preston, Theory of Heat, p. 71, 1904.
Washburn, Prin. Phys. Chemistry, 1915, p. 26.

Debye's Equation

Empirical equation of Nernst and Lindemann.

$$C_v = \frac{3}{2} R \left[\frac{\left(\frac{\Theta}{T}\right)^2 e^{\frac{\Theta}{T}}}{\left(e^{\frac{\Theta}{T}} - 1\right)^2} + \frac{\left(\frac{\Theta}{2T}\right)^2 e^{\frac{\Theta}{2T}}}{\left(e^{\frac{\Theta}{2T}} - 1\right)^2} \right]$$

where

$$\Theta = 136 \left(\frac{T_F}{A}\right)^{\frac{1}{2}} \left(\frac{D}{A}\right)^{\frac{1}{3}}$$

A = atomic wt.
D = density
T_F = abs. melting pt.

Washburn, Prin. Phys. Ch., 1915, p. 259.

Debye—Formulae for Specific Heats

Ann. der Physik., *39*, 789, 1912.

Deslandres Laws

1st. Law. In band spectra, the oscillation frequencies of the lines starting from one head form arithmetical series. More than one such series can proceed from the same head.

2nd Law. The differences in frequency of the heads of the bands in each group form an arithmetical series, but the arrangement of the heads is reversed from that of the lines forming each band.

$$\lambda = \frac{\lambda_0}{1 \pm \left(\frac{m+\mu}{y}\right)^2} \text{ when } \mu = 0$$

Baly, Spectroscopy, p. 613-14, 606, 1912.

Doppler Effect—1843

The apparent change in the wave-length of light produced by the motion in the line of sight of either the observer or the source of light.

Baly, p. 641, 1912.

If two sources emitting harmonic vibrations of the same frequency are moving one toward and the other away from the observer, the frequency of the first source will appear less than that of the second.

The frequency of the light vibrations seen by an observer toward whom they travel ought to appear greater than would be the case if they were at rest.

Thomson, Rays of Positive Electricity, 1913, p. 89.
Campbell, Modern Electrical Theory, 1913, p. 200.

Formula to Express Doppler Effect

$$N = n \frac{v \pm a}{v \mp b}$$

$$\text{Frequency} = \lambda \frac{v \mp b}{v \pm a}$$

where

N = number of oscillations
v = velocity of light
n = frequency of oscillation
a = rate of motion of source
b = rate of motion of observer.

Richardson, Electron Theory of Matter, 1914, p. 304.
Jahrb. d. Radioaktivitat, *10*, 82, 1913.

Doppler-Fizeau Effect—1842

Doppler called attention to the change in the pitch of a sound when the source was moving toward or away from the observer and applied the principle to luminous disturbances radiated from bodies in motion. Principle is used in astro-physical research to determine whether stars are moving toward or away from us.

Wood, Phys. Op., 1911, p. 23.

Drude's Formula

For electrical conductivity.

$x = \frac{1}{2} e^2/m. V.E/\alpha$

V = vibration no. of atom

E = emission no. of atom

α = absorption coef. of an atom.

Electronic theory of metals.

J. Chem. Soc. *114*, ii 288, 1918.

Drude's Theory

Assumes that the electrons cause both the heat and electrical vibrations within metals and that the electrons in the metal follow the same diffusion law as the molecules of a gas.

Schenck, "Phys. Chem. of the Metals," 1919, p. 24

Dufour Effect

Abnormal Zeeman Effect. Has shown that individual lines show Zeeman effect in band spectra, if observed in direction parallel to field and if circular vibrations are converted into plane ones with quarter-wave plate, through Nicol prism.

Wood, Phys. Op., p. 521, 1911.

Dulong and Petit

The specific heats of the several elements are inversely proportional to their atomic weights, i.e., the atom of each of these elements possesses the same capacity for heat.

Roscoe and Schorlemmer, 1913, II, p. 16.

Ebert Effect

Action of ultra-violet light on air space between conductors and cathode.

See Hertz-Effect.

Wied. Ann., *33*, 241, 1888.

Eddy Currents

Whenever a mass of metal is rapidly rotated in a magnetic field its temperature rises, the heat being the direct result of currents of electricity which are induced in the metal, and which are known as "eddy" or Foucault currents.

Slingo and Brooker, "Electrical Engineering," 1908, p. 308.

Edison Effect

A current of negative electricity, increasing rapidly with the temperature, flows from all metallic conductors at a temperature of more than 1000 deg. C. to surrounding conductors, maintained at an equal or higher potential, even if the intervening space is vacuous. This current was first detected by Edison.

Campbell, Modern Elec. Theory, 1913, p. 81–82.

Edison Effect

When a lamp filament is heated a low current will flow to a metal plate located within the lamp and flows only in one way. That is, the cold plate becomes charged with negative electricity which flows from the hot filament.

Einstein Equation

Displacement of spherical colloidal particles.

$$X^2 = \frac{RT}{N}\left(\frac{t}{3\pi r \eta}\right)$$

where

X = horizontal displacement

r = radius of particle

η = viscosity of medium

t = time.

Washburn, Prin. Phys. Chem., 1915, p. 89.

N = Avogadro's number calculated from Brownian movement in liquids $= 5.9 \times 10^{23} \pm 10$ per cent.

Nordlund, Z. physik. Chem., *87*, 59, 1914.

Einstein Hypothesis

In the light-quantum hypothesis of Planck-Einstein one regards the energy of a system of rays, not as spread continuously over an ever increasing surface (wave-front), but as made up of localized centers of energy which move on without subdivision, and can be absorbed only as a whole.

These units of radiation have an energy proportional to the oscillation frequency.

Wood, Phys. Op., 1911, p. 554.

Einstein Theory of Relativity

Richardson, Electron Theory of Matter, 1914, p. 296, 314.
Jahrbuch der Radioakt. u. Electronik, *4*, 435, 451, 1907.
Ann. der Physik, *22*, 183, 1907.
Phys. Zeit., *21*, 88, 1920.

Einstein Theory on Specific Heats

Suggests that all energy stored in simple bodies might belong to a few natural frequencies and on this supposition, he has calculated the specific heats as a function of the frequency of the radiation.

Ann. der Physik. *22*, 180, 1907.
Richardson, Electron Theory, 1914, p. 357.

Elster and Geitel Effect

Clean metal surfaces lose a negative charge when exposed to the action of light, particularly ultra-violet, but retain a positive charge.

The effect is most marked in the case of the electro-positive metals and roughly it is in the order of the metals in Volta's contact electricity series.

Thomson, Recent Researches in Elec. and Mag., 1893, p. 61.
Wied. Ann., *38*, 40, 497, 1889.
Wied. Ann., *41*, 161, 1890.
Wied. Ann., *42*, 564, 1891.

Ettingshausen's Effect (Von Ettingshausen's)

When an electric current flows across the lines of force of a magnetic field an electromotive force is observed which is at right angles to both the primary current and the magnetic field; a temperature gradient is observed which has the opposite direction to the Hall electromotive force.

Richardson, Electron Theory of Matter, 1914, p. 434.

Euler's Theory

A catalyst acts by increasing the concentration of the groups of ions reacting. He assumes that all reactions are ionic.

Kremann, Potts, Applications of Physico-Chem. Theory, 1913, p. 55.

Ewing Theory of Magnetism

Molecules are linked together in groups of two or more molecules, the molecules of each group being held together by the attraction and repulsion of their $N =$ and $S =$ poles.

The magnetization of iron consists in turning the axes of the molecular magnets parallel to the direction of the magnetizing field.

Aldous, p. 635, 1900.
Watson, Gen. Phys., 1918, p. 406.

Fabry and Perot's Étalons

Fixed air layers used as interference apparatus standards, having thicknesses of 2.5 mm., 5 mm., and 10 mm., respectively.

Baly, Spectroscopy, 1912, p. 338.
Ann. Chim. et Phys., 25, 98, 1902.

Faraday Effect

If a plane polarized ray of light passes through certain bodies along the lines of a strong magnetic field, the plane of polarization of the emergent light is different from that of the incident light. In looking from North to South along a line of magnetic force, the rotation is clockwise. On reversing the direction of magnetization, the direction of rotation is reversed.

Preston, Theory of Light, p. 431, 1901.
Campbell, Mod. Elec. Theory, 1913, p. 138.
Experimental Researches of Faraday, Vol. 3, p. 1.

Faraday's Law

Whenever, from any cause whatever, the number of lines of force which thread through any conducting circuit is altered, an electromotive force will be produced during the change in the number of lines, and this will produce or tend to produce a current in the circuit.

Watson, Gen. Phys., 1918, p. 469.

Faraday's Law of Electrolysis—1833

Whenever an electric current passes across a junction between a purely metallic and a purely electrolytic conductor, a chemical change occurs, the amount of which, expressed in chemical equivalents, is exactly proportional to the quantity of electricity which passes and is independent of everything else.

Washburn, Prin. Phys. Chem., *1915*, p. 205.

Faraday's Law for Electrolysis

In electrolysis the quantities of the different substances which separate at the electrodes throughout the circuit are directly proportional to their equivalent weights, and are independent of the concentration and the temperature of the solution, the size of the electrodes, and all other circumstances.

Le Blanc, Electrochemistry, 1907, p. 42.

Fechner Theory of Electricity

A current consists in a streaming of electric charges, vitreous charges traveling in one direction and resinous in the opposite. Like charges attract when traveling parallel to each other and unlike attract when traveling in opposite directions.

Whittaker, "History of Theories of Aether and Electricity," 1910, p. 226.

Fermat's Law

In the case of refraction and reflection, the path of a ray from one point to another by way of a refracting or a reflecting surface is either a maximum, or a minimum. This is true only of plane surfaces.

When the light ray travels from one point to another the ray pursues that path which requires the least time.

Preston, Theory of Light, p. 95, 1901.
Wood, Phys. Op., p. 72, 1911.

Fermat's Law

The path chosen by a ray joining two points is that which can be travelled over in the least possible time.

Aldous, p. 450, 1900.

Fery's Spectroscope

A quartz spectroscope eliminating all lenses by using a prism with curved faces.

J. de Physique, *9*, 762, 1910.
Astrophys. J. *34*, 79, 1911.
Baly, Spectroscopy, 1912, p. 134

Fick's Law

Expresses course of diffusion with same accuracy as Fourier's elementary law.

The fall of concentration p in any infinitely thin layer, at a distance X from any point of reference, should in a given time t satisfy the partial differential equation:

$$\frac{dp}{dt} = K\frac{d^2p}{d^2x}$$

In this formula K represents the coef. of diffusibility which, subject to limitations, is constant for any given solute and solvent, as long as the temperature does not vary.

Mellor, "Higher Mathematics for Students in Chem. and Phys.," 1913, p. 483, 492.

Fizeau Effect

A source of light is physically independent of a spot S in that to an observer relative to whom the source is always at rest the source appears to have exactly the same properties whether it is or is not moving relatively to S, or, the source of light may be at rest relative to S, but between S and the source there may be a material medium through which the light travels and this medium may be in some cases and not in others at rest relative to S. It is found that the velocity with which the light appears to S to travel through the medium differs with the motion of the medium relative to S. This change of velocity is known as the Fizeau effect.

Campbell, Modern Electrical Theory, 1913, 356.

Fleming's Rule

Clench the right hand, then open out the thumb and first two fingers, making them as nearly as possible at right angles to each other. Then place the hand so that the fore-finger points along the wire in the direction in which the current is flowing, and so that the second finger points to the needle, then the thumb points in the direction in which the N-pole of the needle is driven.

Aldous, Elem. Course of Physics, 1900, 721, 825.

Foucault Currents

Whenever a mass of metal is rapidly rotated in a magnetic field its temperature rises, the heat being the direct result of currents of electricity which are induced in the metal, and which are known as "eddy" or Foucault currents.

Slingo and Brooker, "Electrical Engineering," 1908, p. 308.

Foucault's Currents

When a block of metal is moved in the presence of a magnet, induction comes into play and an EMF is set up in various parts of the block and causes currents of electricity to flow within it.

Aldous, p. 767, 1900.

Fourier's Theorem

Determines the law for the expansion of any arbitrary function in terms of sines or cosines of multiples of the independent variable x. If $f(x)$ is a periodic function with respect to time, space, temperature, or potential, Fourier's theorem states that

$$F(x) = A_0 + a_1 \sin x + a_2 \sin 2x + \quad + b_1 \cos x + b_2 \cos 2x + \ldots.$$

This series is an artificial way of representing the propagation or progression of any physical quality by a series of waves or vibrations.

Mellor, "Higher Mathematics for Students of Chem and Phys.," 1913, p. 469.
Aldous, Elem. Course in Phys., 1900, p. 432.
Rayleigh, Phil. Mag., *24*, 964, 1912.

Fowler Formula

Frequency in helium series

$$= 109750\left(\frac{1}{\left(\frac{n_1}{2}\right)^2} - \frac{1}{\left(\frac{n_2}{2}\right)^2}\right)$$

Where n_1 has value of 3 or 4-Helium series in ultra-violet.

Science, *50*, 481, 1919

Fraunhofer's Lines

When sunlight is examined through a spectroscope it is found that the spectrum is traversed by an enormous number of dark lines parallel to the length of the slit. These dark lines are known as Fraunhofer's lines. Kirchhoff conceived the idea that the sun is surrounded by layers of vapors which act as filters of the white light arising from incandescent solids within and which abstract those rays which correspond in their periods of vibration to those of the components of the vapors. Thus reversed or dark lines are obtained due to the absorption by the vapor envelop, in place of the bright lines found in the emission spectrum.

Watson, Gen. Physics, 1918, p. 336.
Baly, Spectroscopy, 1912, p. 11.

Fresnel-Aragon Laws

1. Two rays of light polarized in the same plane interfere in the same manner as ordinary light.
2. Two rays polarized at right angles do not interfere.
3. Two rays polarized at right angles from ordinary light and brought into the same plane of polarization, do not interfere in the ordinary sense.
4. Two rays polarized at right angles (obtained from plane polarized light) interfere when brought into the same plane of polarization.

Wood, Phys. Op., 1911, p. 151.

Fresnel's Integrals (Gilbert)

Table of.

Wood, Phys. Op., p. 247, 1911.

Gauss's Principle of "Least Constraint"

1. The motion of connected points is such that, for the motion actually taken the sum of the products of the mass of each particle into the square of the distance of its deviation from the position it would have reached if free, is a minimum.

2. The motion of a system of material points interconnected in any way and submitted to any influences, accords at each instant as closely as possible with the motion

the points would have if they were free. The actual motion takes place so that the constraints on the system are the least possible. For the measurement of the constraint, during any element of time, is to be taken the sum of the products of the mass of each point by the square of its deviation from the position it would have occupied at the end of the element of time, if it had been free.

Northrup, Laws Phys. Sci., 1917, p. 26.

Mach-Science of Mechanics.
See D'Alembert's and Hamilton's Principle.

Gauss Theory of Errors

Northrup's Laws of Phys. Sci., p. 27, 1917.

Gay-Lussac's Law—1802

The pressure of a gas being kept constant its volume varies directly with the absolute temperature.

$$Vt = V_0 (1+at).$$

Where V_0 = vol. gas at O^0C
Vt = vol. gas at t^0C
for air $a = 0.003665$

Maxwell, "Theory of Heat," p. 29.

The volumes in which gaseous substances combine bear a simple relation to one another and to the volume of the resulting product.

Roscoe and Schorlemmer, p. 75, I. 1911.

Geitel-Elster Effect

See Elster.

Gibbs Theory of Equilibria

Phase Rule—Defines conditions of equilibrium as a relationship between the number of phases and the components of a system. A system has only three independently variable factors—temperature, pressure, and concentration of the components of the system.

A system consisting of n components can exist in $n+2$ phases, only when the temperature, pressure and concentration have fixed and definite values; if there are n components, in $n+1$ phases, equilibrium can exist while one of the factors varies, and if there are only n phases, two of the varying factors may be arbitrarily fixed.

$$P+F=C+2$$
$$F=C+2-P$$

P = no. of phases
F = degrees of freedom
C = No. of components.

Findlay, "Phase Rule," 1906, p. 16.
"Thermodynamics," by F. G. Donnan.

Gladstone and Dale's Law

When a substance is compressed, or its temperature varied, the density alters and there is a corresponding variation in the refractive index.

$$\frac{\text{refractive index} - 1}{\text{density}} = \text{a constant}$$

Preston, Theory of Light, 1901, p. 131.

Glaisher's Factors

For use with wet and dry bulb temperatures.

Kaye and Laby, 1916, p. 39.

Graham's Law

The quantity of a gas which passes through a porous diaphragm in a given time is inversely as the square root of the molecular weight of the gas, or its density.

Ganot's Physics, art. 191, 1893.
Northrup, Laws Phys. Sci., 1917, p. 85.

The rate at which gases diffuse is not the same for all gases, but their relative rates of diffusion are inversely proportional to the square root of their densities.

Roscoe and Schorlemmer, p. 91, I. 1911.

Guldberg and Waage

The reactivity of a substance is measured by its concentration, the greater the concentration, the greater the reactivity.

Different substances have different affinities for each other; these exhibit their value only when they are in immediate contact with each other. The condition of equilibrium depends not only upon the chemical affinity, but also essentially upon the relative masses of the reacting substances.

Nernst, Theoretical Chemistry 1911, p. 447.

When two acids and a base are mixed in equivalent quantities the coefficient of partition ought to be proportional to the square root of the relative strengths of the acids, as measured by means of their catalytic action.

Arrhenius, "Theory of Solutions," 1913, p. 77.

Hallwachs-Hertz Effect

See Hertz Effect.

Has to do with photoelectric emission which varies with thickness of layers showing maxima and minima of emission corresponding to maxima and minima of ultra-violet light.

Le Radium 9, 400-404, 1912.
Sci. Abs., p. 214, 1913.

Halm's Formula

A formula of which the Deslandres, Balmer, and Rydberg formulae are special cases.

$$\frac{1}{n_\alpha - n} = \frac{a_1}{(m+\mu)^2} \pm \frac{b_1^2}{a_1^2}$$

Baly, Spectroscopy, 1912, p. 606.

Hamilton's Principles

The time mean of the difference of kinetic and potential energies is a minimum for the actual path between given configurations as compared with infinitely near paths which might be described (for instance under constraints) in the same time between the same configurations; or more freely: Nature tends to equalize the mean potential and kinetic energies during a motion. While Hamilton's principle involves the conservation of energy, it is much broader in its scope.

Webster, A. G., "Dynamics of Particles and of Rigid, Elastic and Fluid Bodies" 1912, p. 97.

Harkins-Wilson

Equation for atomic weights.

$$W = 2(N+n) + \frac{1}{2} + \frac{1}{2}(-1)^{N-1}$$

Where N = atomic number
W = atomic weight
n = no. of cementing electrons in attaching He nuclei.

For elements of even atomic number the equation becomes

$$W = 2(N+n)$$

J. Am. Chem. Soc., *37*, 1380, 1915.

Hartman's Interpolation Formula

For the determination of the wave-lengths of the lines in a spectrum

$$\lambda = \lambda_0 + \frac{C}{(n-n_0)^{\frac{1}{a}}}$$

Where λ_0, C, n_0 and a are constants.

Baly, Spectroscopy, 1912, p. 158.

Heaviside's Expansion Theorem

$$Y^n = \gamma E \left[\frac{E^{X_1 X}}{X_1 \left\{ \frac{d}{dx_1} O_1 X_1 \right\}} \right]_{-X_1} = A_n$$

Press, Electrician, *83*, 449, 1919.

Hall Effect

When an electric current flows across the lines of force of a magnetic field an electromotive force is observed which is at right angles to both the primary current and the magnetic field.

When a thin rectangular sheet of metal carrying an electric current flowing in the direction of its length is subjected to a powerful magnetic field normal to the sheet, the current stream-lines are deflected toward one edge of the sheet.

The rotation when the light is reflected from Ni or Co, instead of from Fe, is in the same direction as for Fe.

When a steady current is flowing in a steady magnetic field, electromotive intensities are developed which are at right angles both to the magnetic force and to the current and are proportional to the product of the intensity of the current, the magnetic force and the sine of the angle between the directions of these quantities.

Ganot, art. 900, 1899.
Campbell, Modern Elec. Theory, p. 76 and 80, 1913.
Phil. Mag., (5), *12*, 157, 1881.
Recent Researches in Elec. and Mag.
Thomson, 1893, p. 486.
Phil. Mag. Nov., 1880.
Phil. Mag., (5), *19*, 419, 1885. Meas. of Effect.
Richardson, Electron Theory, 1914, p. 434.

Helmholtz Dispersion Theory

The ether is considered as an elastic solid made up of small particles, which when displaced are urged back into their original position by forces of restitution. The refracting medium is assumed to be made up of molecules, between which the ether penetrates freely. The atoms vibrate in periods of their own. The molecules remain at rest, but the atom may be displaced from its position of equilibrium by the vibration of ether and when so displaced is drawn back by a force of restitution proportional to the displacement. Formulae.

Wood, Phys. Op., p. 380, 1911.

Helmholtz Formula

Haber, Thermodynamics of Technical Gas Reactions, 1908, p. 40.

Henry's Law

The quantity of a gas (either weight or volume at N.T.P.) dissolved by a given volume of a given liquid at a given temperature is directly proportional to the pressure under which the absorption takes place.

The quantity of gas which a liquid can dissolve is independent of the nature and of the quantity of other gases which it may already hold in solution.

Northrup, Laws of Phys. Sci., 1917, p. 83
Philips' Physical Chemistry, 1915, p. 20.

Hertz's Theory

Phenomena of elastic impact as statical effect.

Phys. Rev. *12*, 442, 1918.
Hertz's Miscellaneous Papers, English Edition, p. 146.
Love's Treatise on Elasticity, 2nd Ed., p. 195.

Hertz Theory of Impact

Strains produced in the immediate neighborhood of the region of contact are determined by the pressure subsisting at any instant between the bodies and are practically the same as under statical conditions.

Raman, Phys., Rev. *15*, 277, 1920.

Hertz Effect (Wiedemann and Ebert)

Hertz found that a disruptive discharge between two conductors is facilitated by exposing the air space across which the discharge takes place, to the influence of ultra-violet light. W. and E. proved that the seat of this action is at the cathode and that the light produces no effect when the cathode is shielded from its influence, however brightly the rest of the line of discharge may be illuminated. The magnitude of the effect depends on the gas surrounding the cathode.

Recent Res. Elec. Mag. by Thomson, 1893, p. 58.
Wied. Ann. *31*, 983, 1887.

Hertz-Hallwachs Effect

Has to do with photoelectric emission which varies with thickness of layers showing maxima and minima of emission corresponding to maxima and minima of ultra-violet light.

Le Radium, *9*, 400–404, 1912, G. Reboul.
Sci. Abs. p. 214, 1913.

Hertz Waves

An oscillating circuit sends out electro-magnetic waves which have all the properties of light waves, the only difference being that the wave-length is very much greater than that of light waves. The production of these electro-magnetic waves was predicted by Maxwell.

Watson, Gen. Phys., 1918, p. 528.

Hess' Law

The heat of a given reaction is independent of whether it takes place as written, or whether it occurs in stages.

Washburn, Prin. Phys. Chem., 1915, p. 241.

Hooke's Law

As long as a strain is kept below a certain limit for each material, called the elastic limit, the stress is proportional to the strain, and hence, the ratio of stress to strain, that is, the elasticity, is a constant.

Watson, Gen. Phys., 1918, p. 73.

Huygens' Theory of Light 1678

This theory states that light is a disturbance traveling through some medium, such as the ether. Thus light is due to wave motion in ether.

Aldous, p. 505, 1900.

Every vibrating point on the wave-front is regarded as the center of a new disturbance. These secondary disturbances traveling with equal velocity, are enveloped by a surface identical in its properties with the surface from which the secondary disturbances start, and this surface forms the new wave-front.

Wood, Phys. Op., p. 28, 1913.

Joule's Law

The heat produced by the passage of an electric current through a solid metallic conductor is proportional to the product of the resistance of the conductor, the square of the current and the time, or to the product of the applied e.m.f., the current and the time.

$$JH = RI^2t = EIt$$

Where J is Joule's dynamical equivalent of heat, H the number of units of heat, R the resistance of the conductor, I the current, t the time during which the current flows and E the applied e.m.f.

Watson, Gen. Phys. 1918, p. 449

Joule-Kelvin Effect—1852

When a gas expands without doing external work, it is slightly cooled, except in the case of H, which is warmed. Gases in expanding do no interior work.

Preston, Theory of Heat, 1904, p. 375.

Joule-Thomson Effect

The cooling which occurs when a highly compressed gas is allowed to expand in such a way that no external work is done is known as the Joule-Thomson effect. This cooling is inversely proportional to the square of the absolute temperature.

Roscoe and Schorlemmer, I, p. 110, 1911.

Kayser and Runge's Formula

For spectral series.

$$\frac{1}{\lambda} = A + Bm^{-2} + Cm^{-4}$$

This is the first term of a converging series.

Baly, Spectroscopy, 1912, p. 583.

Kepler's Laws

Continuous motion of a body round a point, under the influence of an attraction toward the point, varies inversely as the square of the distance, and the motion is an ellipse. Three following laws were formulated by Kepler:

1. The point towards which the acceleration is directed is at one of the two "foci" of the ellipse.
2. A line (radius-vector) drawn from that point to the moving body sweeps over equal areas in equal times as the body moves; and
3. The time taken to perform a complete revolution in the elliptical path is proportional to the square root of the cube of the mean distance from the central point.

Daniell, Prin. of Phys., 1895, p. 203.

Kerr Effect

When the plane-polarized light is regularly reflected fron either pole of an iron electromagnet, the reflected ray has a component polarized in a plane at right angles to the ordinary reflected ray.

Whittaker, "History of Theories of Aether and Electricity," 1910, p. 368.

Kerr Effect

When plane polarized light is incident on the pole of an electromagnet, polished so as to act like a mirror, the plane of polarization of the reflected light is not the same when the magnet is "on" as when it is "off". It was found that the direction of rotation was opposite to that of the currents exciting the pole from which the light was reflected.

Phil. Mag. (5), *3*, p. 321, 1877.
Thomson, Recent Res. Elec. and Mag., 1893, p. 483.

A positive double refraction similar to that exhibited by quartz in the absence of an electric field, is exhibited by certain liquids.

Wood, Phys. Op., p. 548, 1913.

Kirchhoff's Law

The relation between the powers of emission and the powers of absorption for rays of the same wave-length is constant for all bodies at the same temperature. First, A substance when excited by some means or other possesses a certain power of emission; it tends to emit definite rays, whose wavelengths depend upon the nature of the substance and upon the temperature. Second, the substance exerts a definite absorptive power, which is a maximum for the rays it tends to emit. Third, at a given temperature the ratio between the emissive and the absorptive power for a given wave-length is the same for all bodies, and is equal to the emissive power of a perfectly black body.

Baly, 1912, p. 26.
Preston, Theory of Heat, 1904, p. 588.
Formula for principle of Huygens, see Phil. Mag., *36*, 261, 1918.

Kirchhoff's Laws

1. At any point in a circuit there is as much current flowing away from the point as there is flowing to it.

2. The sum of the several IR drops around any one path of an electric circuit equals the sum of the E.M.F.'s impressed on the same path.

Elements of Elec., Timbie, 1910.
Croft, "Practical Electricity," 1917, p. 138.

Kohlrausch's Law of the Independent Migration of Ions

By adding together the proper ion-conductances one can obtain the Λ_0 value for any electrolyte.

The equivalent conductance of a binary electrolyte is equal to the sum of two values, one of which depends upon the cation, and the other upon the anion.

With increasing dilution the degree of dissociation, and consequently also the equivalent conductance of an electrolyte increases, until complete dissociation and the corresponding or maximum value of the equivalent conductance is reached.

Le Blanc, Textbook of Electrochemistry, 1907, p. 90
Wied. Ann., *6*, 1, 1879.
Wied. Ann., *26*, 213, 1885.
Washburn, Prin. Phys. Chem., 1910, p. 215

Kopp's Law

The molecular heats of all solid bodies are equal to the sum of the molecular heats of the elements contained in them.

Ganot, p. 452, 1899.

At ordinary temperatures the molal heat capacity of a solid compound is approximately equal to the sum of the atomic heat capacities of its constituents.

Washburn, Prin. Phys. Chem., 1915, p. 260.

Kundt's Law

On approaching an absorption band from the red side of the spectrum the refractive index is abnormally increased by the presence of the band, while if the approach is from the blue side the index is abnormally decreased.

Kundt's Rule

With increasing refractivity of the solvent the absorption band moves toward the red end of the spectrum, if the statement is regarded as a rough generalization.

When a pure substance is dissolved in an ionizing solvent the absorption center moves toward the ultra-violet; if a pure substance is dissolved in a neutral, non-ionizing solvent, the absorption center is unaffected, or moves toward the red end of the spectrum.

Wood, Phys. Op., Chap. V, p. 96, 1913.
Northrup, Laws Phys. Sci., 1917, p. 186.

Kundt's Theory

If one colorless solvent has a distinctly greater refractive and dispersive power than a second solvent, then on dissolving an absorbing substance in the two the absorption bands will lie nearer to the red in the case of the first solvent than they do in the case of the second.

The greater number of facts do not obey this rule.

Ann. d. Physik., *4*, 34, 1878
Baly, 1912, 468.

Lambert's Law

Each layer of equal thickness absorbs an equal fraction of the light which traverses it. If we consider layers of the thickness of a single molecule, we can say that each molecule absorbs an equal fraction of the light which passes by it.

Wood, Phys. Op., p. 437, 1913.

Lambert's Light Law

The quantity of radiant energy emitted in the unit of time, by an element of the surface of a body, in any given direction, is proportional to the cosine of the angle between this direction and the normal to the surface of the radiating body.

$J_\varphi = J \cos_\varphi$ where J is total quantity of energy emitted normally and J_φ the quantity emitted in the direction making the angle with the normal.

Northrup, Laws of Phys. Sci., p. 182, 1917.

Langevin Theory (Magnetism)

The molecular circuits of the older theorists consist of electrons revolving in closed orbits within the molecule. In a diamagnetic substance each molecule contains many such orbits, which neutralize each other's actions at external points, owing to the fact that the direction of revolution is different in different orbits. In a paramagnetic substance the neutralization is not perfect, so that the molecule as a whole has a finite magnetic moment. The diamagnetic susceptibility is due to the changes in the nature of the orbits produced by the magnetic field. The paramagnetic susceptibility is due to the orientation of those molecules which have a finite magnetic moment.

Campbell, Modern Electrical Theory, p. 121–127, 1913.

Langley's Bolometer

An electrical resistance thermometer.

Am. J. Sci., (3) *21*, 187, 1881.
Baly, Spectroscopy, 1912, p. 250.

LeChatelier's Law

If some stress (e.g. change of temp., press. or conc.) is brought to bear on a system in equilibrium, the equilibrium is displaced in the direction which tends to undo the effect of the stress.

This applies to all systems and changes of the condition of equilibrium, whether physical or chemical.

Findlay, "Phase Rule," 1906, p. 58.

Le Chatelier

Every external influence arouses in a chemical equilibrium system opposing forces, which, after the ceasing of the external forces, strive to bring it back to its original condition.

Schenck, "Phys. Chem. of the Metals," 1919, p. 151.
Findlay, Phase Rule, 1906, p. 57.

Leduc and Righi Effect

When heat flows across the lines of magnetic force there is a transverse temperature gradient.

Richardson, Electron Theory of Matter, 1914, p. 434.

Leibnitz Equation

This is the most general type of linear equation of the first order involving y and its derivatives only in the first degree.

$$\frac{dy}{dx} + Py = Q$$

Where P, Q are either constants, or functions of X.

Partington, "Higher Mathematics for Chem. Students," 1912, p. 226.

Lenz's Law—1834

When a circuit is moved in a magnetic field in such a way that a change takes place in the number of lines of magnetic induction passing through the circuit, a current is induced in the circuit and a mechanical force is set up such that this force tends to stop the motion which gave rise to the current.

Every action on a system, which, in producing a change in its state, involves a transformation of energy, sets up reactions tending to preserve unchanged the configuration of the system.

Thomson, Elementary Lessons in Elec. and Mag., 1918, p. 476.
Aldous, 1900, p. 763.

Lent's Law

1. The distance remaining the same, a continuous and constant current does not induce any current in an adjacent conductor.

2. A current at the moment of being started, produces in an adjacent conductor an inverse current.

3. A current at the moment it ceases produces a direct current.

4. A current which is removed or whose strength diminishes, gives rise to a direct induced current.

5. A current which is approached, or whose strength increases, gives rise to an inverse induced current.

6. The Law—

If the relative position of two conductors A and B is changed, of which A is traversed by a current, a current is induced in B in such a direction that, by its electro-dynamic action on the current in A, it would have imparted to the conductors a motion of the contrary kind to that by which the inducing action was produced.

Ganot, p. 931, 1899.

Lindemann's Formula

This formula is used for determining atomic heats. It is a modification of the Einstein formula for Atomic heats.

Nernst's Theoretical Chem., 1911, p. 172.

Lissajous's Figures

Graphical curves of simple harmonic motions.

Watson, Gen. Phys., 1918, p. 219.

Lorentz and Fitzgerald Hypothesis

The length of a body in motion relatively to the ether measured against a standard always at rest relatively to the ether is decreased in the ration $1/\beta$. This leads to Einstein's theory of Relativity.

Campbell, Mod. Elec. Theory, 1913, p. 388

Lorenz-Lorentz Relation

$$\frac{n^2-1}{n^2+2}\times\frac{1}{D}=\text{constant independent}$$

of temperature.

Where D = density of the medium
n = index of refraction.

Washburn, Prin. Phys. Chem., 1915, p. 81

Lorentz-Thomson-Zeeman Effect

Since the nature of the light emitted in any direction is determined by the vibrations of the electrons in a plane perpendicular to that direction, an observer receiving light which is traveling along the direction of the magnetic field should find that light composed of two circularly polarized components of frequencies $V'\pm$ (components of the vibrations along axes); the single line in the spectrum which appeared when there was no magnetic field may be split into two lines circularly polarized in opposite directions.

Campbell, Mod. Electrical Theory, 1913, p. 147.

Helium is the only substance which acts exactly according to theory.

Mariotte's Law (See Boyle)—1679

Maxwell's Law

1. Any two circuits carrying current tend to so dispose themselves that they will include the largest possible number of lines of force common to the two.

2. Every electromagnetic system tends to change its configuration so that the exciting circuit will embrace the maximum number of lines of force in a positive direction.

Croft, "Practical Electricity," 1917, p. 144.

Maxwell's Distribution Law

In a system consisting of elastic spheres, i.e. molecules in motion, the result of such motion will be to set up a certain state such that the number (dn) of spheres having velocities lying between $\bar{v}$ and $(\bar{v}+d\bar{v})$ is given by the relation

$$dn=\frac{4n}{a^3\sqrt{\pi}}e^{-\frac{\bar{v}^2}{a^2}}\cdot\bar{v}^2\,d\bar{v}.$$

Where n = total no. spheres in system
e = base of natural log.
a = constant.

In general terms this solves the problem of the distribution of velocities among the molecules of a gas.

Lewis, Phys. Chem., Vol., 1, p. 2, 1916

Maxwell's Law

The components of molecular velocity are distributed amongst the molecules according to the same law as the errors are distributed amongst the observations in the theory of errors of observations.

Preston, Theory of Heat, 1904, p. 72.
Wien, Ann. d. Physik, *58*, 662, 1896.

1. The velocity of the molecules of a given gas is proportional to the square root of the absolute temperature of the gas.

2. Velocities of the molecules of different gases, at the same temperature are inversely proportional to the square roots of the densities of these gases.

$$u=\sqrt{3\,g\,R_0\frac{T}{\delta}}$$

Where g and Ro are constants, T absolute temperature and δ the density of the gas.

Northrup, Laws Phys. Sci., 1917, p. 81

Meyer's Viscosity Equation

$$\eta_t=\eta_0(1+\alpha t)$$

Where α = constant
η = gaseous viscosity
t = temperature.

Kaye and Laby, 1916, p. 31.

Michelson Grating

A diffraction grating made up of glass plates laid together in echelon.

Baly, Spectroscopy, 1912, p. 190.

Minkowski's Theory

This states that time by itself and space by itself are mere shadows, they are only two aspects of a single and indivisible manner of co-ordinating the facts of the physical world.

Harrow, From Newton to Einstein, 1920, p. 62.

Mitscherlich Rule

Isomorphous substances have analogous molecular formulae—not infallible.

Washburn, Prin. Phys. Chem., 1915, p. 68.

Moseley's Laws

Expresses relationship between the X-ray spectrum and the order of an element in the periodic table as follows. the wave-length of the X-ray is inversely proportional to $(N-a)^2$ where N is the atomic number and "a" is a constant.

Kaye—"X-rays," 1918, p. 227.

Nernst Effect

When heat flows across the lines of magnetic force, there is observed an electromotive force in the mutually perpendicular direction.

Richardson, Electron Theory of Matter, 1914, p. 434.

Nernst Heat Theory

Naturwissenschaften, 7, 883, 1919.

Neumann's Law

With chemical compounds of the same formula, and of a similar chemical constitution, the product of the molecular weight into the specific heat is a constant quantity.

Ganot, p. 452, art. 465, 1899.
Preston, Theory of Heat, 1904, p. 296.

Newton's Law of Motion

Every body continues in a state of rest, or of uniform motion in a straight line, unless it be compelled by impressed force to change that state.

Watson, Gen. Phys., 1918, p. 14.

The momentum possessed by a moving body is proportional to the mass of the body and the velocity with which it is moving.

The change in momentum which takes place in unit time is proportional to the impressed force, and takes place in the direction of the straight line in which the force acts.

Watson, Gen. Phys., 1918, p. 15.

Newton's Law

The rate of cooling of a body under given conditions is proportional to the temperature difference between the body and its surroundings.

Preston, Theory of Heat, 1901, p. 155 and 528.

Ohm's Law

The strength of the electric current is equal to the electromotive force divided by the resistance

$$C=\frac{E}{R}$$

Where

C = current
E = EMF of cell
R = resistance of circuit.

Ganot, p. 839, 1899.

Ostwald's Dilution Law

$$\frac{\Lambda^2 C}{\Lambda_0(\Lambda_0-\Lambda)}=\text{constant}$$

Λ = conductance
Λ_0 = equivalent conductance.

Washburn, Prin. Phys. Chem., 1915, p. 217.

Pascal's Law

Pressure exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force on all equal surfaces, and in a direction at right angles to those surfaces.

Ganot, p. 91, art. 97, 1899.

Paschen's Bolometer

This is a very small thermopile with a triple junction of bismuth-cadmium, silver and cadmium-antimony, so suspended that a current causes rotation in a magnetic field

Baly, Spectroscopy, 1912, p. 268.

Paschen's Law

The sparking potential between electrodes in a gas depends on the length of the spark-gap and the pressure of the gas in such a way that it is directly proportional to the mass of gas between the two electrodes—or, the sparking potential is a function of the pressure times the density of the gas.

Thomson's "Cond. of Elec. through Gases," p. 451, 1906.
J. de Physique, *6*, 615, 1907.
Wied. Ann., *37*, p. 79, 1889.

Peltier Effect

If the current is sent through a circuit consisting of two different metals, heat is generated at one junction and absorbed at the other.

When a current flows across the junction of two unlike metals it gives rise to an absorption or liberation of heat. If the current flows in the same direction as the current at the hot junction in a thermoelectric circuit of the two metals, heat is absorbed; if it flows in the same direction as the current at the cold junction of the thermoelectric circuit heat is liberated.

The heat developed at a junction of two metals is proportional to the first power of the current, and depends on the direction of the current.

Eccles, 1918, Wireless Teleg. and Teleph., p. 505.
Thomson, Elem. Elec. and Mag., 1918, p. 449.
Eng'g, *109*, 806, 1920.
Campbell, Mod. Elec. Theory, 1913, p. 71.
Ganot, p. 1014, art. 878, 1899.

Phase Rule

See Gibbs' Theory.

Phlogistic Theory

Refers to alterability of bodies by fire and explains the facts of combustion. All combustible bodies are compounds, so must contain at least two constitutents, one escapes during combustion and the other remains.

Stahl decided that there was only one principle of combustibility and called it phlogiston, meaning burnt.

Roscoe and Schorlemmer, 1911, (I), p. 14.

Pickering Formula—1896

Formula (a modified Balmer's formula) including both of the series of hydrogen lines, that of Balmer as well as his own.

$$\lambda = 4650 \frac{m^2}{m^2 - 4} - 1032$$

Baly, Spectroscopy, 1912, p. 580.
Astrophys. J. *5*, 92, 1897.

Piezo Effect

When certain crystals are compressed between parallel planes, which are at right angles to particular axes, opposite ends of these axes become oppositely electrified. This is known as piezo-electricity.

Love, Mathematical Theory of Elasticity, 1920, p. 147.
Liebisch, Physikalische Krystallographie, Leipzig, 1891.
Mascart, Leçons sur l'électricité et le magnetisme, t. 1. Paris, 1896.

Piezo Effect

Piezo electric effect is an electro-elastic property of certain crystals by means of which mechanical energy may be converted into electrical energy and vice versa.

Pinch Effect

When an electric current, either direct or alternating, passes through a liquid conductor, that conductor tends to contract in cross-section, due to electromagnetic forces. This contracting force is small for relatively low current densities, but is quite large when they become greater, large enough to contract it to zero, that is, to rupture the circuit. This contraction is apt to form locally at some particular spot; it acts like the tearing of a rope at its weakest part; it forms a depression in the channel of molten material; it has the appearance of the liquid being pinched by an invisible force. Into this depression the floating, solid, infusible materials are apt to fall, thereby tending to prevent a reunion of the liquid, and cause a consequent freezing of the charge before the obstacle can be removed.

Hering, Trans. Am. Electrochem. Soc., *15*, 255, 1909.

Planck's Formula for Emissive Power of a Particular Wave-length λ

$$E_\lambda = C\lambda^{-5} / (e^{a/\lambda\theta} - 1)$$

Where

$C = .353$ erg cm² sec⁻¹
$a = 1.445$ cm. deg.
e = the base of the Napierian logs

Planck's Special Distribution Formula

$$\left[J = C_1 \lambda^{-5} \frac{1}{e^{\frac{c_2}{\lambda T}} - 1} \right]$$

Where

J = energy corresponding to wave-length λ
T = Abs. temp.
e = base of natural logarithms
C_1 and C_2 = constants.

Bull. Bur. Stand., *1*, p. 206.
Northrup, Laws. of Phys. Sci., 1917, p. 109.

Poisson's Coefficient

Longitudinal stretching is accompanied by a lateral contraction, and the ratio of the contraction to the proportional stretching is known as Poisson's coefficient. It varies from 0 to 0.5.

Ganot, p. 81., 1899.

Poisson's Integral Formula

Lord Raleigh's Scientific Papers, Vol. 5, p. 193.

Poisson Theory

Electrical phenomena are attributable to two fluids which are contained in all material bodies. Molecules of each fluid repel each other and attract the molecules of the other. The forces obey the law of the inverse square of the distance. At the same distance the attractive power is equal to the repellant. When a body contains equal quantities of 2 fluids they neutralize each other and no electrical effects are discernible.

Whittaker, History of Theories of Aether and Electricity, 1910, p. 59.

Poynting's Law

When a conductor carrying a current is in an electrostatic field, the transfer of energy takes place through the dielectric along paths which are the intersections of the equi-potential surfaces of the electrostatic field with the equi-potential surfaces of the electromagnetic field due to the current.

Northrup, Laws of Phys. Sci., 1917, p. 161.

Poynting's Theory

The velocity with which waves of longitudinal disturbance travel in the air or in any other fluid can be calculated from the resistance to compression and extension and the density of the fluid.

Equation is

$$X = (E - r_o U^2)\ (dy\ dx)$$

Where

X = external pressure

U = resultant relative velocity of propagation

E = elasticity

$\frac{dy}{dx}$ = volume change

r_o = density.

Abbott, Phys. Rev. *16*, 486, 1920.

Prevost's Law of Exchanges

A body is continually radiating energy in every direction and absorbing that which falls on it.

Aldous, Elem. Course of Phys., 1900, p. 406.

Prout's Hypothesis

According to this chemical elements were in reality all composed of hydrogen, basing supposition on the figures for atomic weights adopted at that time (1815) which were in most cases whole numbers. Hypothesis has not been confirmed although of 83 elements in tables, 43 have atomic weights within .1 of a unit of an integral number. The probability of such a condition being fortuitous is 20,000 millions to one.

Roscoe and Schorlemmer (II), 1913, p. 43.

Ptolemy's Law

If a ray of light passes from A to B, striking some point of a plane reflecting surface in its course, and being reflected to B, there is no path from A to B, via any point of the mirror so short as that actually traversed by the ray, under the law of reflection.

Daniell's Prin. of Physics, 1895, p. 133.

Purkinji Effect

Colors appear more saturated at low than at high intensities of illumination. Intensity of sensation is a function of the luminous intensity which differs with the kind of light, that is, the intensity increases and decreases more slowly for the blue than for the red, for the same variation of objective luminous intensity.

If two sources of light, one red and one blue, appear equal at a certain intensity, they will not remain equal if the intensities of both sources be changed in the same ratio.

"Photometry" by Palaz, p. 77, 1896.

Pyro-Electricity

When certain crystals are undergoing changes of temperature, opposite ends of particular axes become oppositely electrified.

Ramsden Eyepiece

An eyepiece for spectroscopic work consisting of two plano-convex lenses placed convex sides towards one another.

Baly, Spectroscopy, 1912, p. 111.

Rankine-Froude

Momentum theory.

Aviation, *8*, 153, 1920.

Raoult's Law of Vapor Pressure Lowering

The relative lowering of the vapor pressure of a solvent which occurs when a solute is dissolved in it to form a dilute solution is equal to the mole fraction of the solute in the resulting solution.

Washburn, Prin. Phys. Chem., *1915*, p. 146.

Réaumur's Scale

This is similar to centigrade with space divided into 80 divisions instead of 100. One degree Réaumur is equal to 5/4 of a degree centigrade.

Ganot, p. 293, 1899

Richardson's Effect

There is a current of negative electricity, increasing rapidly with the temperature, flowing from all metallic conductors at a temperature of more than 1000°C to surrounding conductors, even if the intervening space is completely vacuous. Knowledge of the existence of this current is chiefly due to Richardson. The study of this subject is given the name of thermionics.

Campbell, Modern Electrical Theory, 1913, p. 82.

Righi Effect

When heat flows across the lines of magnetic force there is a transverse temperature gradient.

Richardson, Electron Theory of Matter, 1914, p. 434

Righi Effect

See Kerr.

Rotation of plane of polarized light in magnetic field. Righi has shown that reflected light is not quite plane polarized but is elliptically polarized, the axes of the ellipse being of very unequal magnitude. The amount of rotation depends on the nature of the light, the longer the wave-length the greater the rotation.

Ann. de Chimie et Physique, (6) *4*, 433, 1885; *9*, 65, 1886; *10*, 200, 1887.
Thomson, Recent Res. Elec. Mag., 1893, p. 483–484.

Ritz's Formula

General equation for lines of all substances giving a spectral series.

$$\pm r = N_0\left(\frac{1}{p^2} - \frac{1}{q^2}\right) \text{ where } p \text{ and } q$$

are the roots of certain transcendental equations and N_0 is a constant.

This formula may be used to derive new series of lines from the known spectral series of an element.

$$n = A - \frac{N}{[m + a + B(A - n)]^2}$$

Baly, Spectroscopy, 1912, p. 594.
Phys. Zeit., *4*, 406, 1903.
Ann. d. Physik., *12*, 264, 1903.

Rydberg Formula

For series spectral lines.

$$\lambda = \frac{\lambda_0}{1 \pm \left(\frac{m+\mu}{\gamma}\right)^2} + \frac{\lambda\infty}{1 \pm \left(\frac{\gamma}{m+\mu}\right)^2}$$

Trans. Roy. Swedish Acad., Vol. *23*, No. 11, 1890. Full description.
Baly, 1912, p. 606.

Rydberg—Thiele Formula

See Halm's Formula.

Schuman's Emulsion

A special silver bromide emulsion which when applied to a plate very thin, is sensitive to the extreme ultra-violet up to $\lambda = 1200$ tenth meters.

Wien. Ber., *102*, II, A994, 1893.
Baly, Spectroscopy, 1912, p. 374

Seebeck—1821

If a circuit consists of two metals, one junction hotter than the other, a current flows in the circuit. The direction of the flow depends on the metals and the temperature of the junctions.

Pidduck, "Treatise on Electricity," 1916, p. 204

Seebeck Effect—1821

When two wires of different materials are twisted or soldered together at their ends so as to form a complete circuit and one of the junctions is heated, an electric current flows in the circuit. If the junction is cooled, a current flows, but in the reverse direction.

Aldous, "Course in Physics," 1900, p. 794.

Sine Law—1621

See Snell's Law.

Snell's Law—1621

1. When light passes from one medium to another, the incident ray, the normal to the surface at the point of incidence, and the refracted ray are all in the same plane.

2. The sine of the angle of incidence bears to the sine of the angle of refraction a ratio which is constant for the same two media, and depends only on the nature of those media

$$\frac{\text{Sin } i}{\text{Sin } r} = \mu, \text{ index of refraction}$$

i = angle incidence
r = angle refraction.

Aldous, p. 529, 1900.

Sollas Theory

Valency volume theory.
Atomic structure of salts.
See Barlow and Pope.

Roscoe and Schorlemmer, p. 222, II, 1913.

Stark Effect

A change occurs in the number of spectral lines when the emission takes place in a strong electric field. The phenomena are different for different lines and the observed effects depend upon the geometrical relation between the direction of emission and the direction of the electric field. When the lines H_α and H_β are under observation in a direction perpendicular to the electric field, it is found that five lines appear instead of each original line. When the radiation is observed in the direction of the electric field three evenly spaced lines appear which are unpolarized.

Physik. Zeit, *6*, 892, 1905.
Richardson, Electron Theory of Matter, 1914, p. 534
Ann. der Physik, *43*, 965, 1914
Ann. der Physik, *43*, 983, 1914
Ann. der Physik, *43*, 991, 1914
Ann. der Physik, *43*, 1017, 1914.
Ann. der Physik, *21*, 451, 1906

Stefan's Law

The total radiation of any body is proportional to the fourth power of its absolute temperature.

Preston, Theory of Heat, 1904, p. 590
Watson, Gen. Phys., 1918, p. 365.

Stefan's Law

The total radiant energy emission from bodies varies as the fourth power of the absolute temperature, i.e., the energy per unit volume, in vacuo, of the radiation in equilibrium in an enclosure at the absolute temperature T, is equal to a universal constant A multiplied by the fourth power of the absolute temperature

$$L = AT^4$$

Richardson, Electron Theory of Matter, 1914, p. 334.
Wiener, Ber. *79*, 391, 1879.

Stefan-Boltzmann

The energy radiated in unit time by a black-body is proportional to the fourth power of the absolute temperature.

$$E = K(T^4 - T_0^4)$$

Where E = total energy radiated by the body at absolute temperature T to the walls of an enclosure at absolute temperature T_0 and K is a constant.

Preston, Theory of Heat, p. 590 and 596, 1904.
Northrup, Laws Phys. Sci., 1917, p. 107.
Wied. Ann., *63*, 395, 1897.

Stoke's Formula

For determining volume of single drop—derived from the velocity of fall of a minute spherical body in terms of its radius, r, and viscosity η of the medium in which it falls. The formula is

$$u = \frac{2}{9} \cdot \frac{g r^2}{\eta}$$

Where u = velocity of fall of the body
g = acceleration due to gravity.

Hering's "Electrochem. Equivalents," 1917, p. 78.
Millikan, Electron., p. 53, 1917.

Stoke's Law

$$v_1 = \frac{2ga^2}{9\eta}(\sigma - \rho)$$

η = viscosity of medium
a = radius
σ = density of drop
ρ = density of medium.

Millikan, "Electron," p. 88, 1917.
Wood, Phys. Op., p. 559, 1913.
Houstoun, Treatise on Light, 1915, p. 257.

Sutherland Formula for Gaseous Viscosity

$$\eta_t = \eta_0 \frac{273 + C}{\theta + C} \cdot \left(\frac{\theta}{273}\right)^{\frac{3}{2}}$$

Where θ = Absolute temp.
C = Sutherland's constant
η = gaseous viscosity
t = temperature

Formula holds for temperatures above the critical and for pressures such that Boyle's law is approximately obeyed.

$$\theta = \frac{K\,\theta^{\frac{3}{2}}}{\eta} - C$$

Where K is a constant.

Fisher, Phys. Rev., 1907, 1909
Kaye and Laby, 1916, p. 31.
Phil. Mag., *31*, 1893

Taylor's Theorem

Determines the law for the expansion of a sum or difference of two variables in terms of a series of ascending powers of one variable.

Partington, "Higher Mathematics for Chem. Students," 1912, p. 172.

Thomson Effect

The phenomenon of the appearance or disappearance of heat when a current flows from a cold towards a hot part of a conductor. In unequally heated copper, heat is liberated at a point when the current and the heat flow in the same direction, and is absorbed when they flow in opposite directions.

When an electric current flows along an unequally heated metallic conductor it tends, in the case of copper, to diminish the inequality of temperature and in the case of iron to increase this inequality.

If a current is passed through a uniform, homogeneous conductor in which a temperature gradient exists, heat will be generated on one side of the heat maximum and absorbed on the other. On which side the heat is generated depends on the direction of the current and on the material of the conductor.

Eccles, Wireless Teleg. and Teleph., 1918.
Watson, Gen. Physics, 1918, p. 534.
Worthing, Phys. Rev. N. S., Vol. *5*, 445, 1915.
Thomson, Elements Elec. and Mag., 1918, p. 454.
Ganot, p. 1016, 1899.
Eng'g, *109*, 806, 1920.

Trautz

The intensity of the light emitted is proportional to the velocity of reaction. Many reactions are accompanied by light phenomena if a high velocity of reaction is assured.

Zeit. f. Elektrochemie, p. 534, 1908.

Trouton's Law

For different liquids the latent heat multiplied by the molecular weight is approximately proportional to the absolute temperature. The molecular latent heat is proportional to the absolute temperature.

Preston, Theory of Heat, p. 391, 1904.

Tyndall's Phenomena

If a beam of light enters a darkened room in which dust particles are floating, its path is rendered evident by the scattering of the light at the surface of the particles; each one of these appears as a bright moving speck. This effect is used to detect colloidal solutions. The light which is scattered is partly polarized.

Philips' Phys. Chem., 1915, p. 192.

Van der Waal's Equation

Modification of simple gas equation $pv = RT$ applicable only to a perfect gas.

$$\left(p + \frac{a}{v^2}\right)(v - b) = RT$$

where

$\frac{a}{v^2}$ = effect of mutual attraction of molecules and b = volume of gas when compressed to the utmost possible extent.

p = pressure
v = volume
T = absolute T
R = constant depending on gas taken
V = Molecular vol. of all gases 22.425 litres at 0°C. and 760 mm.

Mills, Realities Modern Sci., p. 223, 1919.
Venator, Zeits. Phys. Chem., *93*, 242, 247, 1918.

Van't Hoff's Law

When the temperature of a system in equilibrium is raised, the equilibrium point is displaced in the direction which absorbs heat.

Findlay, "Phase Rule," 1906, p. 57.

Verdet's Constant

In the rotation of light in a magnetic field the direction of rotation is determined by the nature of the medium and the direction of transmission, and is proportional to the difference of magnetic potential between the points where the ray enters and leaves the medium.

$$\theta = r H l$$

where

θ = rotation of beam of light in minutes
r = Verdet's constant
H = strength of magnetic field in gausses
l = length of path transversed in cms.

r is proportional to the square of the wave-length.

Preston's Theory of Light, 1901, p. 133.

Voigt Effect

The displacement of the outer components of the Zeeman triplets plotted against the strength of the magnetic field is represented by a hyperbola, approximating asymptotically to a straight line in strong fields.

Baly, Spectroscopy, 1912, p. 556.

Volta Effect

When two metals are placed in contact with one another in the air, one becomes positive and the other negative, though the charges are feeble.

Elem. Lessons in Elec. and Mag., S. P. Thompson, 1918 p. 14.
Bridgeman, Phys. Rev. *14*, 406, 1919.

Von Ettingshausen's Effect

When an electric current flows across the lines of force of a magnetic field an electromotive force is observed which is at right angles to both the primary current and the magnetic field. A temperature gradient is observed which has the opposite direction to the Hall electromotive force.

Richardson, Elec. Theory of Matter, 1914, p. 434.

Von Veimarn's Law

The degree of dispersion and the general physical appearance of crystalline precipitates are always the same irrespective of the chemical nature of these precipitates, provided that the precipitation takes place under *corresponding conditions*. This is the law of corresponding states for the crystallization process.

Washburn, Prin. Phys. Chem., 1915, p. 368.

Wave Theory of Light

See Huygens's.

Weber's Theory of Magnetism

Thinks that iron and steel individual molecules are minute magnets each with a N-pole and a S-pole. When iron is unmagnetized the molecules are arranged at random, there being on the average equal numbers of molecules facing in all directions. When iron is magnetized, the molecules are twisted round more or less, so that a large number face in the same or nearly the same direction.

Aldous, p. 635, 1900.

Wehnelt Electrode

Platinum foil covered with calcium, strontium or barium oxide for use as cathode in a vacuum tube.

Phys. Zeit., *6*, 690, 1905.
Baly, Spectroscopy, 1912, p. 436.

Weinstein Formula

For determining inductance of coils in high frequency electrical measurements.

Wied. Ann., *21*, 329, 1884.
Bur. Stand., *8*, 137, 1912.

Weiss on Paramagnetic Atoms-magnetons

Molecules of paramagnetic substances differ, not in the nature of the uncompensated electronic orbits which they contain, but simply in the *number* of such circuits, which are always of the same nature. An uncompensated electronic orbit having the moment "B" is called by Weiss a "magneton." It may be represented by an electron revolving in an orbit of radius 10^{-8} cm. with a period of about 10^{-14} sec. $B = 16.4 \times 10^{-22}$ c.

Campbell, Mod. Electrical Theory, 1913, p. 128.

The magnetic properties of substances arise from the presence of an ultimate unit, the "magneton," in the atoms of the substance. The same substance may contain different numbers of magnetons at different temperatures.

Richardson, Electron Theory of Matter, 1914, p. 394.

Werner's Theory

An atom possesses two kinds of valency, viz., principal valency, which is concerned with the combination of atoms or radicals which can exist as ions, or are equivalent to ions, and supplementary valency, which is concerned with the combination of radicals which cannot exist as ions.

Roscoe and Schorlemmer (II), p. 37, 1913.

Wiedemann and Franz

At any temperature the ratio of the thermal conductivity of a body to its ohmic conductivity is approximately the same for all metals, and the value of the ratio is proportional to the absolute temperature.

Whittaker, "History of Theories of Aether and Electricity," 1910, p. 457.

Wiedemann Effect

Action of ultra-violet light on air space between conductors and cathode.

See Hertz Effect.

Recent. Res. Elec. and Mag., Thomson, p. 58, 1893.
Wied. Ann., *33*, 241, 1888.

Wien's Law

The relation expressed by the following equation

$$\lambda_m T = \text{a constant}$$

where

λ_m = wave-length corresponding to the maximum of the energy curve of radiation

T = absolute temp.

is known as Wien's law.

Watson, Gen. Phys. 1918, p. 365.

Wien Radiation Formula

Weid. Ann., *58*, 662

Willans Law

When the total steam consumption at different loads is plotted as ordinates, the loads being abscissae, the result is a straight inclined line cutting the axis of ordinates at some distance above the origin of co ordinates, this distance representing the steam consumption due to cylinder condensation at zero load.

Kent, Mechanical Engineers Pocketbook, 1916, p. 991.

Wilson Nuclei

Compound molecules with constitution H_4O_2, H_6O_3, H_8O_4, found in steam.

Eng'g. (L) *108*, 483, 1919

Young's Dynamical Theory of Light in Crystals

An impulse is propagated through every perpendicular section of a lamellar elastic substance in the form of an elliptic undulation.

Whittaker, "History of Theories of Aether and Electricity," 1920, p. 111.

Young's Modulus

The force which would be required to stretch a body of unit cross-section to double its length if such lay within the elastic limit. It is a constant for any one material.

$$M = \frac{LF}{ea}$$

where

L = length of body
a = area of cross-section
F = stretching force applied
e = total elongation produced by F.

Ganot's Physics, art. 87, 1899.
Northrup's Laws Phys. Sci., p. 19, 1917.

Young's Theory of Light

See Huygens's.

Zeeman Effect

Sodium lines are broadened slightly when the flame is placed between the poles of a powerful electromagnet and the edges of the broadened line show traces of circular or plane polarization depending on whether the observation is made along or at right angles to the lines of magnetic force.

Pidduck, "Treatise on Electricity," 1916, p. 621.

Zeeman Effect—1896

When a source of monochromatic radiation is placed in a strong magnetic field the lines of the spectrum are widened and many spectral lines may be broken up into multiple lines.

When the spectral lines are observed in the direction of the magnetic field, the components of lower frequency exhibit right-handed, and those of higher frequency left-handed, polarization, showing that the vibrators are negatively charged.

When the light is examined in a direction perpendicular to the lines of force, the edges are found to be plane-polarized, from which the conclusion may be drawn that with a sufficiently strong field the line will appear triple. The two outer components are polarized with their vibration directions perpendicular to the lines of force, while the central component vibrates along the lines of force.

Houstoun, Treatise on Light, 1915, p. 284.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy ol an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Arc Welding

Progress of Welding in the Shipyards. Bonner, William T.
Mar. Engng., Jan., 1921; v. 26, pp. 57-65.
(In the main, a summary of progress in the art. Includes table showing record of arc welding work of the Bethlehem Shipbuilding Corporation, Ltd.)

Balancing

Martin Rotor Balancing Apparatus.
Engng. (Lond.), Dec. 31, 1920; v. 110, pp. 864-865.
(Illustrated description of a British apparatus.)

Corona

Determining Corona Voltages for Actual Lines. Peek, Jr., F. W.
Elec. Wld., Dec. 25, 1920; v. 76, pp. 1258-1259.

Eddy Currents

Simple Theory for Arriving at the Additional Losses in Slot Conductors of Alternating Current Machinery. Pohl, Dr. Robert. (In German.)
Elek. Zeit., Nov. 18, 1920; v. 41, pp. 908-910.
(Simplifies the formula derived by A. B. Field and published in the A.I.E.E. Proc., July, 1905; pp. 659-686.)

Electric Cables

Maximum Allowable Working Voltages in Cables. Davis, Charles W., and Simons, Donald M.
A.I.E.E. Jour., Jan., 1921; v. 40, pp. 12-22.
(Includes tabulated data of maximum voltage stress in various cables.)

Research on the Heating of Buried Cables.
Elec'n. (Lond.), Dec. 24, 1920; v. 85, pp. 738-742.
(Abstract of technical report presented to I.E.E.)

Electric Condensers

On Electrostatic Transformers and Coupling Coefficients. Blake, F. C.
A.I.E.E. Jour., Jan., 1921; v. 40, pp. 23-29.
(Mathematical paper on the theory of condenser phenomena.)

Electric Conductors

Use of Aluminum for Electric Lines. (In French.)
Génie Civil, Dec. 18, 1920; v. 77, pp. 509-511.
(Condensed account of the properties of aluminum as they affect its use in transmission lines.)

Electric Drive—Rubber Mills

Application of Electric Power to the Rubber Industry.
A.I.E.E. Jour., Jan., 1921; v. 40, pp. 35-47.
(Report of A.I.E.E. Sub-committee of the Industrial and Domestic Power Committee on the Rubber Industry.)

Electric Drive—Steel Mills

Slip Regulators vs. Notchbacks. Gage, Gordon.
Assoc. Ir. & St. Elec. Engrs., Dec., 1920; v. 2, pp. 11-19.
(Gives the results of experiments on control of a 1500-h.p. wound-rotor induction motor in a steel mill.)

Electric Drive—Textile Mills

Power Applications to Cotton-finishing Plants. Loeb, Leo.
Mech. Engng., Jan., 1921; v. 43, pp. 5-8.
(Analysis of the generation of power and its application.)

Electric Locomotives

On Vibrations in Electric Locomotives Provided with the Crank Drive. (In German.)
Elek. Zeit., Dec. 9, 1920; v. 41, pp. 976-979.
(Discusses the general theory of such vibrations and methods of prevention.)

Electric Meters

Wattless Power Meter. Haase, Paul. (In German.)
Trua, Dec. 15, 1920; v. 2, pp. 90-92.
(Describes and illustrates a new meter which, when used with the usual watthour meter, shows the amount of reactive power used.)

Electric Motors, Induction—Slip

Liquid Slip Regulator. Scott, Guy F.
Elec. Jour., Jan., 1921; v. 18, pp. 37-38.

Electric Transformers

Factors in Selecting Transformers for Various Services. Hollister, V. L.
Elec. Rev. (Chgo.), Dec. 18, 1920; v. 77, pp 951-954.

Electrical Machinery—Temperature

Allowable Temperature Rise for Motors. Phillips, H. M.
Power, Jan. 11, 1921; v. 53, pp. 62-65.

Electricity—Rates

Question of Charges for Reactive Power. Scoumanne, F. (In French.)
Revue Gen de l'Élec., Jan. 1, 1921; v. 9, pp. 14-23.
(Concerned with the theory of various methods of charging the consumer for wattless power. Serial.)

Sale of Electric Energy on the Basis of Power-factor of the Subscriber's Load. Bargeton, P., and Genkin, V. (In French.)
Revue Gén. de l'Élec., Dec. 18, 1920; v. 8, pp. 863-869.
(On the theory of charging for electric energy according to the amount of active and reactive load. Describes wattmeter for such purpose.)

Fuels

Fuel and Its Conservation.
Mech. Engng., Jan., 1921; v. 43, pp. 22–31, 38.
(A group of papers on supply, conservation, distillation, etc., of fuels. Includes useful statistics on coal supply.)

Insulators

Operating Performance of Insulators on a 45,000-volt System. Vincent, H. B.
A.I.E.E. Jour., Jan., 1921; v. 40, pp. 30–34.
(Illustrated paper showing data on performance in service.)

Load Factor

Effect of Load Factor on Station Costs. Junkersfeld, Peter.
Elec. Wld., Jan. 8, 1921; v. 77, pp. 85–88.

Measuring Instruments

Testing Hardness of Bearings and Journals.
Iron Age, Dec. 30, 1920; v. 106, pp. 1727–1730.
(Describes the construction and use of an instrument called the "michrocharacter" for testing hardness.)

Nozzles

Pressure-flow Experiments on Steam Nozzles. Mellanby, Prof. A. L., and Kerr, William.
Inst. Engrs. & Shipbuilders, Trans., Dec., 1920; v. 64, pp. 1–41.
(Lengthy paper presenting test results.)

Power-factor

Phase Compensation with Special Reference to Polyphase Motors. Fynn, Val. A.
A.I.E.E. Jour., Jan., 1921; v. 40, pp. 48–64.
(On the theory and practice of improving power-factor by phase compensation.)

Radio Stations

Lafayette Radiotelegraph Station at Croix-d'Hins, near Bordeaux. Cabanne. (In French.)
Génie Civil, Dec. 11, 1920; v. 77, pp. 473–482.
(Lengthy, illustrated description of apparatus and equipment; also wiring diagrams. See also plate VI.)

Railroads—Electrification

Status of Heavy Traction Abroad.
Elec. Rwy. Jour., Jan. 1, 1921; v. 57, pp. 31–36.
(A summary, by countries, of the electrification situation abroad.)

Relays

Protection Against Unnecessary Opening of the Circuit Due to Short Circuits and Overloads. Sterr, P. v. d. (In German.)
Elek. Zeit., Dec. 16, 1920; v. 41, pp. 1002–1004.
(Describes and illustrates a relay which opens only the defective portion of a distribution system.)

Statistics—Electric Furnaces

Status of the Electric Steel Industry. Cone, Edwin F.
Iron Age, Jan. 6, 1921; v. 107, pp. 69–71.
(Extensive statistics on electric furnace installations in the United States and Canada.)

Steam Turbines

Small Steam Turbine. London, W. J. A.
Engrs. Soc. of W. Pa. Proc., Nov., 1920; v. 36, pp. 539–573.
(Illustrated paper on the principles of construction and operation of turbines up to 300 h.p.)

Strength of Materials

Radiology Applied to the Testing of Materials. Fleming, A. P. M., and Clarke, J. R.
Engng. (Lond.), Dec. 24, 1920; v. 110, pp. 850–852.
(Shows the possibilities and methods of testing materials by means of X-rays. Serial.)

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GENERAL ELECTRIC REVIEW

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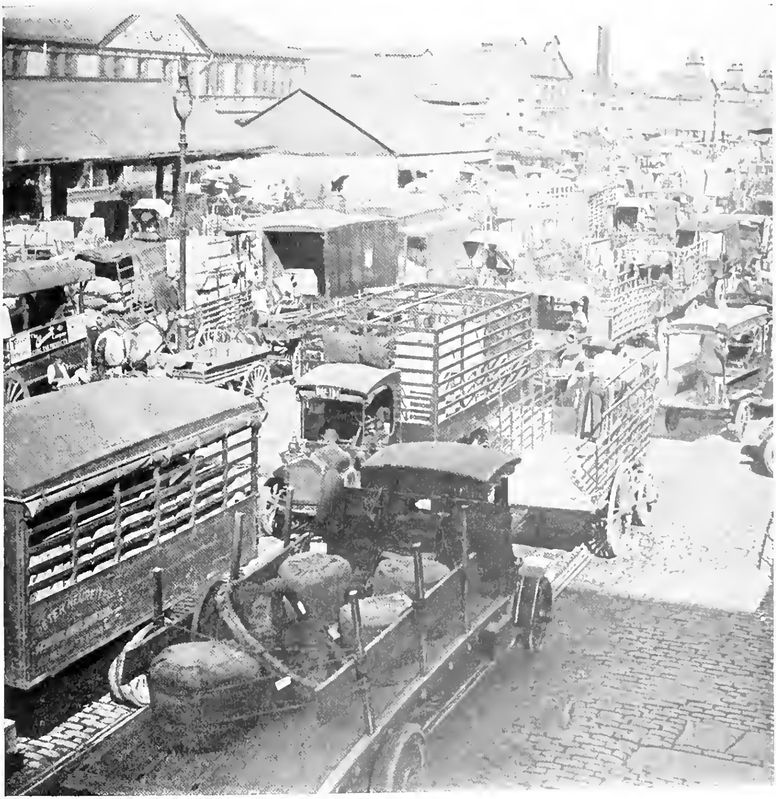
APRIL, 1921



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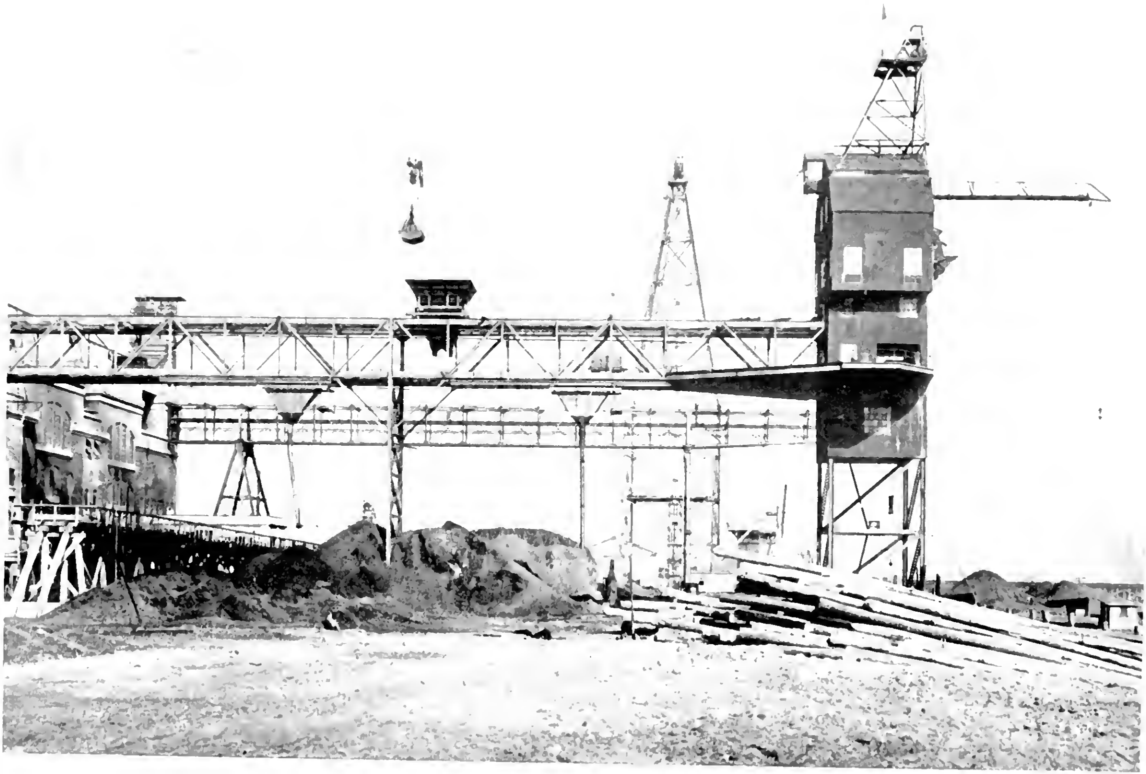


Mead Morrison Coal Tower and Lidgerwood Cableway at Plant of the Baltimore Consolidated Gas, Electric Light and Power Company. General Electric Alternating-current Motors and Control Used. Bucket in Closed Position. Capacity, 350 Tons Per Hour

GENERAL ELECTRIC REVIEW

ELECTRO-MECHANICAL *TRANSFERATION*—A PANACEA

By Zenas W. Carter

Sales Director, Austin Machinery Corporation

Zenas W. Carter

There is an element of grave danger in the economical program now fantastically governing the actions of boards of directors, public officials and bankers. It is the danger that the current idea of right-and-left slashing to reduce costs will brush aside the greatest lesson for the benefit of mass humanity which has emanated from the emergencies of the past few years. That lesson, learned during the pressure of doing the seemingly inpossible in industry, was the need for conservation of human physical energy.

For several years America made goods and transported them with phenomenal rapidity. This speed was made possible through the use of what may be termed *electro-mechanical transferation*. Labor shortage compelled us to devise and utilize mechanical equipment and machines to replace physical energy of human beings. Under the pressure of emergency, men of affairs approved the installation of progressive production methods, authorizing engineers and superintendents to initiate and devise mechanical means to take up the burden of man-power shortage.

Electricity played such a direct part that all the producing facilities of the entire electrical industry were utterly inadequate to meet the demand. The shortage of motors of all sizes, as well as of other types of electrical equipment was so great that companies made promises of deliveries months or years ahead, in a hopeful way, but almost without expectation of fulfillment. While no figures are available, it is easy to understand that a major proportion of this insatiable demand was to meet the requirements for mechanical transference.

Suddenly, because of an over-speculation in raw materials, the controlling powers of the financial world and of the producing world—almost in a panic—ordered, directed and suggested that buying cease. The first reaction from this nervousness was forgetfulness, and this forgetfulness now causes the electrical industry to suffer. Men everywhere forgot or waived aside the figures which engineering departments had gathered to prove that in each industry and in each division of our commercial life the economical loss, from labor waste due to inefficient methods of handling materials and commodities, was tremendous. These figures are just as true today as they were a year ago.

The general methods of handling goods in transport, whether by rail or water, are obsolete, expensive, and tend constantly to congestion; and they will in future create congestion, as in the past. These methods, and the ineffective methods of handling materials in industry at large, lay a dollars-and-cents burden of waste upon the entire American public which is staggering.

To be specific, there is a waste loss suffered through inadequate material handling and goods handling methods in the port of New York alone (as one engineer has estimated), exceeding $100,000,000 per year. The waste loss through inefficient methods of handling freights on our railroads would probably add $400,000,000. The waste from inadequate methods of handling raw materials at producing centers and handling parts in process of production and finished products in our industrial plants is practically inconceivable, but undoubtedly many times greater than our transportation waste loss.

The bearing which all of these facts have upon the electrical industry is to emphasize the need that the entire personnel of the electrical industry be marshalled as a force to resurrect the discarded recommendations and plans of our economic engineers, in order to bring recognition of the fact that this is still the most important single factor in price reduction.

While it is true that buying in all channels is for the moment held in suspension, it is equally true that there is not a thought in the minds of the public at large, nor in the mind of the most careful student, that the civilizing progress of the past few years shall not continue. All peoples, in all lands, have come to demand more. The realization of the demand is merely in abeyance for the moment. Men and women who have learned in the past decade that travel enlightens the mind will continue to demand such compensation in return for their labor as will permit the exercise of this civilizing and uplifting influence.

Men who have bought silk shirts and new automobiles; families who have moved into larger quarters; children who have enjoyed the expanding and helpful influence of a wider and more extensive acquaintance and social life—all these luxuries and comforts aroused latent emotions and activities of human beings are expanded beyond the point where it will be possible again to compress them into the narrow channels of the past.

The way to meet this expansion is open only in one direction—increased production. For the moment labor may be plentiful, but even at the present time there is no economy in the employment of human beings to perform service which may be rendered by mechanical means. The electric industrial truck makes it possible to handle raw materials and finished parts in a factory at much less cost than was formerly required for six or eight men to perform the same work with wheelbarrows.

But this economy is not all. The economy in the conservation of the physical space required is of itself a great factor in cost reduction.

The overhead electric travelling-crane, the electric locomotive crane, the electric hoist, the continuously-operating conveying machinery, the progressive production made possible by a co-ordination of electrically operated conveying, hoisting, trucking and mechanical production systems of assembly—all requiring electric motors and all of the electrical equipment necessary to produce the current and feed it to the operating mechanisms—are necessary and potent factors which industry will find it is essential to use in order to meet the wave of demand for reduction in prices.

Within the past few weeks the first test set of uniform containers for handling express packages from store-door to store-door, without re-handling, has moved between New York and Chicago. Within another decade the endless handling and re-handling of miscellaneous packages and commodities into and out of express cars, box cars and freight stations, and the loading and unloading of individual units on to and off of trucks, will be a thing of the past.

In the handling of express alone, on all the railroads of the United States, by this unit container method, the demand on the electrical industry for motor equipment to operate the overhead travelling-crane systems necessary for electric motor trucks to facilitate the transportation of the goods from the steam railway cars to destination, and the handling of the unit containers at destination, will prove to be a very important percentage of the volume of electrical business.

The transference of raw materials from cars to storage, and of raw materials and parts in process of manufacture from one point of need and one operation to another in our industrial plants, and the re-modelling of our industrial plants to meet the needs for progressive production methods, will all tend to add more and more to the necessity for expansion in the Electrical Industry.

Fully ninety per cent of all modern material handling and mechanical transportation devices are electrically operated. The opportunity exists almost endlessly throughout the United States for the central station, for the manufacturer of electrical goods, for the electrical-goods jobber and the individual salesmen, to be important factors and a civilizing influence in the human uplift of the next generation—which will come through the increased production of all goods and the reducing of prices on all goods that these mechanical methods will make possible.

Every way-station, every railroad transfer point, every raw material producing center (mine, field or forest), every industrial plant, is an electrical opportunity. A little thought, a careful analysis of conditions, a study of mechanical transferation machinery already invented and in use, and the opportunity will present itself to suggest a change in the methods of transferring which will help reduce the ultimate cost of the finished product to the consumer.

The unemployment problem itself will be solved by this elimination of human beings from the necessity of expending physical energy on work which can be performed by electro-mechanical methods. This seems a paradox. History, however, proves that the demand for all things increases in proportion to the economy of its production. In addition, as human beings are released from the inertia and stagnation of routine performance, their mental acumen increases proportionately, and this increased activity of the mind's perceptions produces a corresponding increased demand for additional luxuries and comforts—and civilization makes its progress through the increase of the aspirations of the human being.

This increased demand has been proved for generations in the textile industry; in the printing industry, as represented by the development of the linotype machines to supersede type-setting by hand; in the automobile industry, as illustrated by the development of automatic production as compared with wagon-building by hand.

As the production of the individual increases through the use of mechanical methods, the correspondingly increasing demand automatically creates the opportunity for full employment of the individual.

Present unemployment, therefore, is largely the result of an attempt on the part of the mass to restrict its individual unit production and consumption without recognition of the fundamental principle that this mass action automatically results in a corresponding stagnation.

Electro-mechanical transferation, the transfer of things by mechanical devices, electrically operated, is therefore a panacea! Its influence for betterment in industry is coordinate with its influence for the benefit of mankind! Its functioning completely, as a panacea, merely awaits more action by more men with this vision! Already its potential influence is in motion.

PORT DEVELOPMENT AND THE CENTRAL STATION

By Chas. K. Nichols

New York Edison Company

Chas. K. Nichols

In the future, the growth of the Central Station Industry will, to a very large degree, consist of opening up and developing industries and applications, not so much where the electric motor merely supersedes some other form of motive power, but where new and better methods are found for carrying on many operations, relieving human labor of much of its burden and increasing the utilization of capital by decreasing the time required to perform these operations.

One development that promises much from the standpoint of the utilization of the service of the central station is that of the efficient mechanical handling of materials.

Not long ago, *The Literary Digest* announced that, from a survey that it had just completed, it was evident that only about five per cent of the potential demand for material handling machinery has been met. Further facts brought out by this survey show that there is an actual, although perhaps unrecognized need for over two hundred thousand pieces of apparatus, including industrial trucks and tractors, hoists, stackers, conveyors and cranes; that only five per cent of the plants in the United States are using such machinery to any extent. It has been estimated that if this apparatus, for which a real need exists, were put into service the sale of energy would exceed five hundred million kilowatt-hours per year for this work alone.

Apart from the general subject of material handling throughout all the industries, the one phase that is now attracting considerable attention is the mechanical handling of freight at docks and at railroad terminals. We are beginning to realize the fact that the usual handling equipment on our piers has not kept pace with other industrial developments.

The possibilities of building a large and attractive load for the central station may be seen if we consider the large amount of mechanical apparatus installed at a modern terminal. The port of Seattle has more mechanical equipment than any other port in the United States, with the exception of New Orleans, and at this latter port the machinery is highly specialized for handling a few commodities, principally bananas and cotton. At Seattle, however, miscellaneous freight is handled and the economy has far surpassed that of any other port. The equipment here consists of derricks and cranes of different types, elevators, tractors, conveyors, as well as a complete refrigerating plant for a cold storage warehouse. The electrical equipment consists of one hundred and fifty electric motors, with a total of 3500 h.p.

It may be that the future development of the warehouse is forecast by the type of seaboard terminal constructed during the war for the army supply bases. Consider, for example, the base at Boston. Here a storehouse was built which was one of the largest reinforced-concrete buildings in the world, being eight stories high and 1638 ft. long by 126 ft. wide, with a pier shed composed of two 3-story sections, each 924 ft. long by 100 ft. wide. Here the electrical equipment consists of 40 industrial storage battery tractors, 46 electric freight elevators, six passenger elevators, 24 winches and four semi-portal bridge cranes. The substation is designed for an initial load of 4500 kv-a. and an ultimate load of 10,000 kv-a.

An idea of the amount of energy that would be required on the water front is given in a recent study of conditions at the Port of New York. It is estimated that about 45,000,000 tons of freight are moved into and out of the port each year. Tests show that a ton of freight may be hoisted from the hold of a steamer and placed on the pier, or the reverse, at an expenditure of 0.5 kw-hr.

If the most modern electrically operated equipment were used, this operation alone would mean a consumption of 22,500,000 kw-hr. per year. To this would be added all energy required by tractors or cranes of some type for moving the freight and the other appliances used to meet special conditions. Thus, for water borne freight alone, the annual use of energy might easily reach 50,000,000 kw-hr.

The figures given do not include the freight moved by rail, which at this port is found to be 76,000,000 tons, and the railroad terminals are large consumers of power. Adding to the figures already given the amount of energy required for this part of the total tonnage, gives an idea of the enormous amount of potential business we have at our doors.

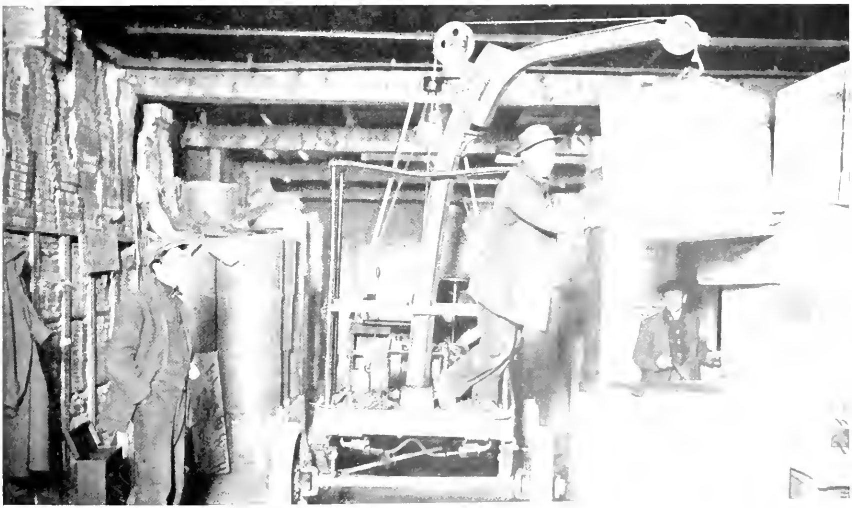
In the United States we are today preparing to spend over one hundred and fifty million dollars for new piers, wharves and other facilities for taking care of and speeding up our enormous shipping, and between fifty and one hundred million dollars for new warehouses. For economical freight handling, these should be equipped with all of the modern machinery that engineering talent has made available.

Only by concerted effort, however, can this be accomplished, for there is a very strong tendency to continue to follow old and inefficient methods. It may be that the charge that our methods lack efficiency and are out of date, may be questioned by those who will point to a few of our notably efficient installations, including the wonderful machinery now in use at the ore docks of some of the steel companies.

We have made rapid strides in the development and use of machinery for handling bulk freight, and the finest examples in the world of machinery of this class was to be found here. For miscellaneous cargos, however, it is generally true that our progress has been slow, but we can look forward to wonderful possibilities in the future.

The central station industry cannot expect that this will come without careful study of conditions, active promotion, and a continuous sales effort on the part of everyone interested. The load possibilities are there, however. Bringing them to light may seem a slow and laborious process, but the results that may be achieved are well worth any expenditure of time and effort, no matter how great.

Sprague Electric Freight Truck Carrying 48 Cases of Canned Goods which as shown is Equivalent to 12 Hand Truck Loads



Battery Truck Crane Employed in Tiering Cases in the Plant of the Eastern Manufacturing Company, South Brewster Me

Sea Ports: Their Organization and Administration

By Calvin Tomkins

Ex-Port Commissioner, New York City

While the geographical location of a sea port will always have an influence in its selection by a shipper, the patronage it receives will be determined more and more by the extent of the public facilities which it offers the shipper for warehousing, grading, reshipment and banking credits. With such facilities a port is equipped to establish itself in favor and can readily be administered so as to reap the many direct and related benefits that accrue to principal shipping centers. In treating this subject in the following article, the author furnishes a number of examples and analyzes them in connection with the unprogressive methods still in vogue in many of our sea ports. The latter section of the article he devotes to a discussion of material handling by machinery.—Editor.

Primary Port Functions

The sea ports of the world are the points of international contact, and since ocean transportation has become so cheap and regular that its cost as regards all but bulky and heavy commodities is almost negligible, a new significance has been acquired by a few of the great ports as centers both for manufacture and distribution. Railroads and ships converge at the great ports and the consequent opportunities which have been opened for the receipt of raw materials and the shipment of finished products are causing them to develop into great industrial centers. London, Hamburg, and New York are the notable examples of the working out of this process.

In proportion as the services which ports render to the commerce of the world are public services, as distinguished from private gainful services, are they likely to attract commerce and increase their importance.

Montreal, New Orleans and Seattle are the primary North American ports where such public services have been most liberally provided and where organization and administration are best adapted to public use, while New York, under the influence of its great commercial bodies, affords the unique example of the most badly organized and most selfishly administered great port of the world, functioning as it does primarily as a private profit-mongering corporation for the benefit of monopolists, and only secondarily as a sea port.

New Orleans provides public warehousing, grading, re-shipment facilities and banking credits for shippers of cotton and grain, which are available for every small farmer along the line of every connecting railroad. Montreal does the same as regards grain and like Seattle is providing public cold-storage for perishable foods. This will make impossible the maintenance of food monopoly like the great Atlantic fish monopoly which centers at Boston, or the food monopoly distribution made possible by the rings of private cold-storage warehouses which surround New York and most other cities just as the ring of Octroi stations surrounds Paris. The association of banking facilities with a well organized public system of warehousing and grading has done much to build up the trade of London, Hamburg, and Antwerp. Great quantities of commodities are sent to these ports from all over the world (especially in dull times) simply for storage during the hold-over period and are then reshipped on order when trade improves.

Public wholesale terminal markets are beginning to develop at some cities into which all lines of transportation are conducted and which are provided with cold-storage adjuncts for surplus stocks. Such markets tend to lower living costs and to make labor more available and contented.

Principles of Port Organization. Deep and safe channel approaches from the sea, easy grades and convenient rail approaches from the land, and the protection of a safe roadstead are, of course, prerequisites for sea port development. With the exception of Montreal and Philadelphia the primary ports are located near the sea, since the capital investment in the largest type of ocean craft (which are the most economical carriers) demands a quick voyage, and a quick turn-around at the end of the voyage to realize the maximum economy of service.

Waterways, such as the Mississippi, the Erie Canal and the Hudson River and the Welland Canal, have in the past contributed largely to the success of the ports at which they terminate.

Their necessary competitive interference with railroad revenues under private ownership has for the time being resulted in neutralizing their great potential importance as transportation factors (except as the rail service may be temporarily disorganized and use made of the waterways to relieve congestion) and they will doubtless continue of relative unimportance until the railroad system shall have been nationalized, when it will become a matter of indifference, except for economies, whether freight shall be moved by waterway or by rail. It will then as a matter of course be routed whichever way may be most advantageous to the transportation system considered as a whole. The land and water services will then be administered as related parts of a unified transportation system.

Sea port organization everywhere is largely a matter of planning for a belt-line terminal railway service—or a series of concentric belt-lines—about the port, intersecting all railway lines and providing a cheap and rapid interchangeable car service, which shall connect factories, warehouses, transshipment sheds, docks and markets with each other and with all carriers. Such a belt-line service is in operation at Montreal and at Canadian ports generally, because the railroads have been nationalized, and also at New Orleans. The other United States ports, except New York, are striving with varying degrees of success to attain it.

Ports should be organized each as a public administrative unit, at which all terminal, trans-shipment and transportation services—and ultimately warehousing—shall be conducted under the single authority of one public administrative organization. The most successful primary ports are those which have most nearly attained this objective.

The economies gained by such unified organization supplemented by the most modern methods of handling freight, as noted below, can be capitalized and the proceeds used for shore front acquisition and improvement without the imposition of burdensome taxation upon the local community. The public acquisition of riparian lands and submerged areas and their subsequent reclamation and adaptation to commercial and industrial uses has greatly facilitated port financing and development. Notably is this true at Boston, San Francisco and Los Angeles; and still greater possibilities are to be found in the reclamation of the neglected marsh and submerged lands about the port of New York.

Next in importance to the establishment of a continuous belt-line freight movement and a single public administration for each port is provision for ample storage back of the piers or quay walls at which the ships lie. So rapidly has the size of ships increased that the lack of adequate storage for cargo in and out has become a most serious defect at many ports in North America.

Cargo must be accumulated and sorted for convenient loading in anticipation of the arrival of the ship, for the quick turn-around is the basic fact of port efficiency. The ship on arrival must also be discharged with the utmost expedition and the incoming and outgoing cargoes must not interfere with each other and block free movement. Docks and piers are too limited and, generally speaking, too costly to serve these two functions of rapid loading and unloading, consequently there must be provided amply spaced transshipment sheds and warehouses adjacent to the ship's berth, or expensive delays will be incurred. The limiting factors which control speed of unloading and loading are the rapidity with which cargo can be broken out of the hold of a ship and delivered to the slings under the hatches for hoisting out, and the rapidity with which cargo can be taken from under the hatches and stowed in the hold of a ship.

All the other processes of cargo handling outside of the ship should and can be speeded up to these limitations of breaking-out and stowing cargo.

The war-constructed terminals of the United States Government at Boston, New York, Philadelphia, Norfolk, Charleston and New Orleans have provided for this need and the ports at which they are located will greatly profit not only by the added facilities, but by the examples afforded of modern port organization on a large scale. These government stations should not be jobbed out for private exploitation but should continue to function locally as public utilities.

Mechanical Handling

The growing disparity between terminal handling and distribution costs on the one hand and the cost of the line haul on the other, for both rail and water borne freight, is an economic phenomenon of the present time which deserves more than passing attention. Carriage costs have gone down while terminal charges have gone up.

Marine carriers have suffered more from this change than have rail carriers because service by water is more irregular, the units are larger, and the processes of loading and unloading a boat are more complicated than are the processes of loading and unloading a car.

Modernizing terminals and transfer stations and the substitution of mechanical handling machinery in place of manual labor and the employment of less labor casually and more labor continuously are the only remedies. Unskilled labor well organized as it now very generally is, resembles dynamite rather than steam power in its actions and reactions whenever trade is very "bad" or very "good"

Little has so far been accomplished towards modernizing terminals except at a few western cities and at some of the war bases of recent construction.

Much, however, has been accomplished by the introduction of freight handling machinery: instance the tractor and trailer, the micro elevator, belt conveying machinery, hoists, cranes, and tiering machines. Experience has shown that the availability of mechanical handling is being retarded more by the lack of standardized unit containers than by any other cause.

At New Orleans, for instance (which is the best organized and administered sea port in the country) you may observe grain, cotton, coffee, sugar, bananas, and a few other articles handled by machinery with ease and at minimum cost into and out of warehouses constructed for particular terminal uses. Even at New Orleans, however, this is not the case so far as general package freight is concerned. Here labor costs mount rapidly as human intelligence and greater liberty of movement become necessary to handle a multitude of packages varying in size, form, weight, strength, and character of contents and construction. In short, machinery has been successfully designed for special services but not for the general service of commerce. Factory handling where packages are uniform presents problems comparatively easy of solution, but at water and rail terminals involving transfers between warehouses and the inconvenient holds of ships and interiors of box cars, the problem has not been solved and the rule of hook and hand truck still continues.

The remedy will be found to be the introduction of a standardized unit container in the form of a demountable closed auto truck body, which can be readily transferred by cranes to and from railroad flat cars, auto chassis, warehouse floors and vessels. The vertical and horizontal terminal movements involved in handling such containers are simple and capable of accomplishment by equipment now generally in use. Some reorganization of terminals will be necessary but, as The Motor Terminals Company has demonstrated at Cincinnati, this will be neither complicated nor expensive. Labor costs for handling such standardized unit containers represent a very small part of the present outlay necessary for the handling of miscellaneous package freight.

The horizontal movement of freight at terminals has recently been revolutionized by the substitution of industrial tractors and trailers for the hand truck, and standardized containers will make this new practice even more feasible. Vertical movements of freight between different floor levels will be greatly facilitated by the use of a standard container.

The growing complication of switching movements between congested city terminals tends to increase in geometrical ratio as the volume of business increases in arithmetical ratio, and it is now evident that there must be a physical limit to the possibility of switching cars. These transfers between local terminals can be expedited and cheapened, as B. F. Fitch has demonstrated at Cincinnati, by the use of demountable auto truck bodies between the terminals.

The water front generally and the transshipment sheds and railroad transfer points should be electrified so that electric power, which is so much more convenient, economical and efficient than steam for these intermittent functions, should everywhere be made available from central stations at moderate cost.

The need of the railroads for increased revenues will probably compel them at an early date and with the ready approval of the Inter-State Commerce Commission, to separate haulage charges from terminal handling charges. These two kinds of services are now lumped together, although the disparity between them has increased enormously in recent years.

A few years ago the terminal charge was incidental, now it is the principal expense. When this separation shall take place it will compel unprogressive terminal cities to modernize their methods of freight handling or see their trade go elsewhere. New York in particular will then suffer the consequences of its long drawn out profiteering port policy.

Fair Principles of Freight Rate Making and Their Effect on Our National Marine Terminal Problem*

By John Meigs

President of Terminal Engineering Society

"One great stumbling block in the way of the introduction of genuine economies in the transference of marine-rail cargo, and of efficient port planning in general, has been the fact that no special incentive has heretofore been established for making such reforms. By deliberate concert of both rail and marine companies absolutely inefficient ports have been favored by special free services on the part of these transportation agencies, and thereby enabled to compete for freight tonnage on more advantageous terms than better and more efficient ports not so favored." "A continuance of the present extravagant, wasteful, unscientific and unfair policy of port charges would be an anachronism, and would mean merely the preservation of an indefensible, feudal system of practically legalized highway robbery." These quotations from the following article clearly set forth a phase of the national marine terminal problem which is pernicious in its effect and must be eliminated before our export and import facilities can be brought to a healthy state of development.—Editor.

John Meigs

ONE of the most startling of the many disconcerting discoveries made by the American people concerning themselves during the recent war, and one of the least flattering to their pride as supposedly capable business organizers and operators, was the appalling lack of efficiency displayed by their general transportation system, including both rail and marine lines, under the stress then applied to it. In both instances this low factor of efficiency applied most particularly in connection with the terminal handling and storage aspects of transportation rather than in the performance of the mere long distance transference of freight from one point to another.

The general condition of traffic engorgement at practically all transfer points throughout the United States, and the tying up of unnumbered thousands of railroad cars at these yards for indefinite periods because of the inability to promptly unload them at the seaboards were shocking, but the congestion at inland points was but a marker to that at our principal ports.

When called upon to meet the extraordinary demands of the war for transportation of men, munitions and supplies to our army overseas and the armies of our allies, it was found that the concentration of freight at a few of our greater ports—particularly the country's principal port, New York—was so intense and overwhelming that conditions at these points of transfer between rail and marine carriers became alarming. The habit of generations past, of forcing a large proportion of our total export and import commerce through the narrow bottle-neck of a few favored seaports, had created a condition that, instead of being—as the original proponents of the system doubtless argued—one tending along lines of maximum economy and despatch, worked in a manner exactly to the contrary of these surmises, and was both slow and costly in the extreme.

Railroads which had been encouraged in many cases to neglect their natural ports of ingress and egress for foreign goods and had become habituated to carrying freight past these normal outlets to ones further removed, either because of the desire to avail themselves of the additional revenues derivable from the longer haul, or for other and more complicated reasons, found their lines and terminals congested beyond any previous conception of the possibilities of the case, and the movement of rail freight, both for domestic and foreign delivery, suffered a condition of partial paralysis that resulted in serious embarrassment to the railroads and to the nation.

Piers and railroad yards so filled up with cars awaiting unloading, with no reasonable chance for being reached for weeks ahead, produced a backwater congestion at the seaboard which ended in a condition approximating complete stagnation at many points. That these conditions have been relieved to some extent since the war is due more to the better general distribution of freight movement rather than to any physical improvement in terminal facilities. These still continue as bad as they were at the time of the partial collapse of our transportation system at the moment of the country's greatest need.

For fifty years no sensible improvement has been made in the quality of our system of handling freight at terminal points, which still remains in all essential particulars as our fathers' fathers knew it. Nor has the quantity of terminal facilities of any char-

* Abstract of Inaugural Address.

acter been materially increased at the points where most needed in the last decade. Rail haul facilities, however, are distinctly superior on nearly all of our roads to the terminal equipment for loading, discharging and storing freight, and the great problem has always been to get the freight out of the terminals and in motion on the rails.

It has been asserted by one official investigator of the subject that of the more than two billion dollars spent per annum in antebellum days on the movement of rail freight, four-fifths of it was consumed by delays at terminals, some necessary, others useless. This expert figures out that the American freight car spends year in and year out eleven out of every twelve hours standing still. Thus more than ninety per cent of the life of every freight car is now consumed in switching operations, in standing idle on side tracks, in loading or unloading its contents, or in repair shops.

The average rail movement of our freight cars has been approximately twenty-four miles per day. In war days, under the most vigorous efforts of governmental and railroad authority, this daily movement was advanced only to an average of twenty-six miles per day. These conditions maintain, despite the fact that the only time that a freight car is making money for its owners is while it is under way transferring goods from one point to another.

The logical conclusion from these facts is that railroad cars are on an active earning basis less than ten per cent of the time. It is manifest to the merest tyro that this average daily movement of twenty-four or twenty-six miles in twenty-four hours, or at the average speed of about one mile per hour, cannot be due to the inability of the railroads to transport cars between terminal points at a very much faster rate of movement than this. Even at the unstandardized speed of the slowest freight trains, this distance could be accomplished in approximately two hours of actual train time, leaving the other twenty-two hours of the day unaccounted for except by terminal delays.

Most strenuous efforts are now being made by the roads, since their return by the Government to their original managements, to increase this average car mileage and also the average load per car carried previous to and during war times. The present railroad ambition is reported to be to bring the loading of cars up to an average of 30 tons, and the movement of them to an average of thirty miles per day, an improvement of more than twenty per cent in both particulars. These reforms must necessarily be brought about mainly by improved methods at the terminals.

On account of these expensive delays it has been roughly estimated that the cost of handling freight at rail terminals is equal to, if not greater than, the entire cost of its rail haul; that is, after cars have been delivered at a terminal yard following a rail movement averaging for export freight several hundred miles, it will then cost as much to deliver it the short distance between the receiving yards and the local terminal delivery points as it did to transport it the entire rail distance through which it moved in its entire journey. Effective reform in this wasteful system can be brought about in but one way, that is, through the increased efficiency of terminal handling; for as pointed out, the relative time spent in rail movement and in terminal stagnation of cars is so enormously disproportionate that this fact is self evident.

As far back as 1912, James J. Hill said in an address before the Railway Business Men's Association: "Every interest and every community should understand that the main need today of transportation and of the many activities connected with and dependent upon it, is an increase of terminal facilities. It is no exaggeration to say that the commerce of the country, its manufacturing and agricultural industries, its prosperity as a whole, and the welfare of every man in it who engages in any gainful occupation, can escape certain disaster only by such additions to and enlargements of existing terminals at our great central markets and our principal points of export as will relieve the congestion that now paralyzes traffic when any unusual demand is made upon them."

These words, it is needless to point out to my readers, were prophetic, and the bitter consequences of inaction in this line of needed improvement predicted by Mr. Hill have been fully realized. We commoner mortals were but slowly arriving at a realization of the coming consequences that this great railroad genius had foreseen and predicted nearly a decade previously, when the stress of a great war both convinced and aroused us on this point, and has impressed every student of the subject with a belief in the absolute necessity for radical action in the correction of these deficiencies, in order to render impossible in future a repetition of such a disastrous experience as we have only recently passed through.

The transportation lessons which the war has taught us, and well taught us I believe, may be briefly outlined as follows: First, the necessity for more efficient handling of freight at both marine and rail terminals, that is, the quicker despatch of both cars and ships by their hastened discharging and reloading; and, second, the proper development on our seaboard of as many ports as are qualified by natural and industrial conditions to economically perform the necessary functions of a transfer station between marine and land cargo.

The fallacy of the over-centralization of freight facilities at one, or even several great ports, has been so thoroughly exposed by recently past events that but little additional argument is needed along this line. The old custom of concentrating the freight movement of the country at a few local points is seen to have been a costly and disastrous mistake. In future an effort should and doubtless will be made to discontinue this senseless habit and to use the lines of shortest possible movement between our ports and the nearest points of origin or distribution of the freights carried in vessels resorting thereto.

One great stumbling block in the way of the introduction of genuine economies in the transference of marine-rail cargo, and of efficient port planning in general, has been the fact that no special incentive has heretofore been established for making such reforms. By deliberate concert of both rail and marine companies absolutely inefficient ports have been favored by special free services on the part of these transportation agencies, and thereby enabled to compete for freight tonnage on more advantageous terms than better and more efficient ports not so favored. Rates for marine-rail freight have been established without regard to the actual cost of the services performed, and many ports capable of economical development have been refused the opportunity of deriving benefit from their natural advantages by discriminatory rates in favor of naturally inferior rivals.

The reasons which have led to these unfair and unwise discriminations and to the setting up of these false gods in transportation economics—or uneconomics—need not be reviewed at length at the present time, reflecting back, as many of them do, to the old days when the system of rebating in many forms and of free services of sundry kinds to favored individuals or communities was a universally established one in transportation affairs. These unfair advantages still persist in many ways and many places, but public opinion now frowns upon them; they are being rapidly legislated out of any possibility of long continuance, and in future it may safely be assumed that ports to be successful must be able to demonstrate genuine ability to handle expeditiously and economically the cargo passing over their piers and through their railroad yards.

As General William M. Black, formerly Chief of Engineers, U. S. Army, strikingly says in a recent address: "One rate of charge to one man and another rate of charge to another man for the same amount of service is unfair. This is taxation. One man is overcharged, in order that another may be rendered more prosperous. It is the same for communities. Why should one community be favored by railroads more than another? What right has any set of private individuals to use powers granted by the people at large in an endeavor artificially to offset natural advantages of location? If one locality has such natural advantages that its earning possibilities are greater than another, why should it not enjoy them? . . . The whole proceeding appears to me entirely contrary to our conception of the ideas of government."

Apparently no serious effort has been made by the transportation corporations to ascertain what the various classes of service performed by them actually cost. All of the various terminal operations are lumped in with the rail haul cost and rates established at such a figure as to be inclusive of all of them. This naturally is inimical to progress in the scientific improvement of terminal conditions, and puts a premium on inefficiency in terminal handling that has made it difficult for any great progress to be made in this most important branch of the transportation art.

The only way in which a port can maintain a successful existence, if not equipped either by natural endowment or by the industry and far-sightedness of its citizens, with the ability to economically handle the freight passing through it, is by the assistance of unfair advantages allotted to it by the transportation companies—either marine or rail—by means of which its own natural or artificial disadvantages may be overcome at the expense of the entire remaining portion of the public served by these transportation organizations. A port at which the cost of handling freight is materially greater than at other and competing ports has no logical and legitimate reason for continued preeminence. If it is not so favored by nature, and so equipped by man, as to enable it to compete on a fair, above-board basis with other ports in the same general coastal section it should be permitted to retrograde in rank and, if necessary, to disappear completely from the list of transfer points for overseas freight.

The practical basis for abolishing the old system of favoritism and donations to special interests lies in the institution of a more scientific system of freight rates, by which the terminal costs of handling of freight at seaports may be segregated from the rail-haul costs and proper charges made to cover the actual expense of each and every service rendered.

The contention sometimes made on this subject, that the present zone system of rates is the only practicable one and that it is impossible to definitely ascertain the costs of the various services rendered by rail transportation companies, is absurd and is a reflection upon the intelligence of railroad operators. If it were a fact that the variations in terminal handling costs in different communities are immaterial and measurable in terms of cents per ton, this contention would be correct and the game would not be worth the candle. But when, as partial investigations show, there are differences of several hundreds per cent in the cost of handling the same classes of freight in different cities—varying in cases cited by the Interstate Commerce Commission from as low as $1.80 per car for terminal handling to as high as $35 per car—such incontrovertible evidences of uneconomic conditions cannot be ignored.

The present zone system of rates, while possessing undoubted advantages in the simplifying of railroad bookkeeping, and of undeniable benefit on general principles where the services rendered to the various communities included in one zone are substantially equal, is not fair where the zone limits are violently stretched to include within them specific communities the physical surroundings of which are such that service thereto is materially more expensive than to others in the same zone.

The system of the furnishing of transportation services to certain communities at less than cost means simply of course that this expense is absorbed into the general operating budget of the railroads furnishing the services, and that these terminal costs, instead of being assessed against the shippers on whose account they are incurred, are distributed broadly among all of the users of these roads regardless of whether they have derived the slightest benefit from them.

No better scheme could be devised for placing a premium upon inefficiency and for discouraging sound economics in port development than to continue indefinitely the senseless system of ignoring terminal costs and fixing a rail-haul zone rate sufficiently large to include all costs incurred of every kind, whether these are genuinely necessary or not. If we are to have a substantial improvement in our port terminal conditions, some system of rate making must be devised by which ports that have been enterprising enough to institute genuinely efficient methods can be rewarded for their intelligence and far-sightedness; and, on the other hand, that ports whose aim is to be supported in their inefficiency by unwilling tribute exacted from the country at large may be penalized to such an extent that they will be forced to mend their ways, upon pain of commercial decadence.

There are gross inefficiencies in the handling of rail and marine freight at practically every port in this country, as our general methods of cargo handling are in many respects archaic and crude in the extreme. There are, however, very radical variations in the degree of inefficiency in different ports, and at least some of our coast cities must be given credit for recent broad-minded and intelligent constructive policies in the development of their opportunities, and a vast improvement in standards of construction and operation over those in general vogue. At the other extreme, however, are port communities which have persisted in transacting their marine-rail business along lines of maximum resistance and minimum economy regardless of reason or expense. Among these of course the principal sinner is the port of New York.

Our smaller ports, provided they are large enough to afford well balanced facilities, are in fact more economical to operate than the large and overgrown ones can possibly be. As an example, Montreal and New Orleans, with their officially controlled and operated harbor belt line railroads, transfer cars from any receiving yard in the city to any point on the waterfront for a flat charge of $5 per car, and make money at it. Even Philadelphia, with a belt line system but poorly organized and dependent upon the tender mercies of the competing railroads for its actual physical operation, can move cars to any point on the waterfront for but slightly more than the above amount. The country's welfare is largely dependent on the development and increase of our smaller ports.

As Dr. Robert J. McFall, of the University of Minnesota, states: "Investigations already made have clearly demonstrated that the terminal service is not one that is subject to decreasing costs per unit of service as the service is increased; it apparently follows exactly the opposite rule. As traffic increases in the large terminals, it becomes increasingly more costly per unit to handle it; and complexity and congestion bring decreasing economies in their train.

"And yet the present system of neglecting costs in rates to terminals is artificially stimulating the growth of these large centers of population. The *burden* of transportation costs is on the country in general; the large center gains the advantage. The large centers getting their service at less than cost, the general business of the country is taxed to build up the large cities, to perpetuate and increase a more expensive system of conducting our business, to make their burdens in turn still greater to support these centers in the future. We may be sure the railways themselves do not pay this extra cost. They cannot. They are not in charity work."

The figures of terminal costs previously quoted, while not of guaranteed detailed accuracy, are at least measurably correct. The sums represented by them are so huge as to baffle the imagination in conceiving what they really mean, but certainly to the dullest intellect it must be evident that there exists a most threatening situation in our entire terminal system, and one that should have the earnest and most concentrated attention of the business men and engineers of the country until at least a half-way satisfactory solution of the problem is reached.

A scientific study should be made, under the auspices of a competent commission, to ascertain the actual terminal costs of freight transfer in every port in the country as compared with the rail haul costs; and a policy of ruthless elimination of unfit ports be started upon. Efficiency and economy alone should be made the standards for judging the desirability of ports, and no mere deference to the fetish "established business interests" should permit the country to delay the working out of a practical policy toward this end.

Only in this way can the intelligence and ambitions of the citizens of our port cities be stimulated to such a point that the rail and marine terminals will be placed in a condition of genuine efficiency. Such a policy would place a premium on properly designed and located railroad yards, upon an effective interchange system of freight between the various railroads entering ports by means of belt line roads, and upon the proper location, design and equipment of piers and quays for the transfer of land and marine cargo.

A continuance of the present extravagant, wasteful, unscientific and unfair policy of port charges would be an anachronism, and would mean merely the preservation of an indefensible, feudal system of practically legalized highway robbery. It should and must be rooted out.

The Need for Organization by Material Handling Machinery Manufacturers: An Opportunity

By Frederic Stadelman

Wellman Seaver Morgan Company, New York City

Mr. Stadelman first refers to the handling of material in bulk and points out that in the development of machinery for this purpose each manufacturer has acted independently of the others. He explains the reasons why successful results have been possible of attainment in this field by such methods, and then shows why the conditions existing in the field of package freight handling prevent an adequate solution of this problem by like methods of attack. Nevertheless, efforts in the development and application of package freight handling machinery have been expended in an isolated rather than collective fashion with the result that there is nowhere available complete and accurate knowledge of the subject to apply to the general proposition of handling miscellaneous freight. The author, in concluding, makes a strong plea that this condition be remedied by organization of the interests concerned.—Editor.

Frederic Stadelman

Since the ending of the war the growth of interest in machinery for handling freight at railroad transfer points and marine terminals has been remarkable. The country is coming to realize the enormous waste that exists in transferring package freight through terminals. Many seaports both on the Atlantic and on the Pacific Coasts have appointed commissions to investigate the possibilities of machinery for reducing terminal costs. Several hundred millions have been appropriated in the United States alone for port improvements. Newspapers have repeatedly emphasized the necessity of adopting modern machinery at marine terminals. Public attention has been focusing on the subject. The need of development of our ports is readily grasped by the individual. The average man can easily picture the importance of loading and unloading ships economically; he has seen it done often in the movies. The subject is spectacular and appeals to the imagination. A casual acquaintance only with the fundamental factors is sufficient to enable the average person to understand the necessity of improving existing methods.

The public at large, however, does not realize yet that handling package freight economically at railroad transfer points is a bigger problem and involves much greater tonnages than at the seaboards. The difficulties in railroad transportation, however, and the delays caused by freight congestion, car shortage and strikes are now beginning to bring home the need of economically handling all classes of railroad freight at every transfer point. The public is slowly appreciating the fact that the expense of transporting the necessaries of life is really a big item in the cost of living. Notwithstanding the development of machinery in this country for handling bulk material, the adoption of devices for transferring miscellaneous freight has been backward to a degree. The engineering genius and manufacturing skill that have created and perfected the marvelous bulk handling machinery in use was largely centralized in single plants. Successful bulk handling machinery was designed and built under one roof by the engineers of single self-contained organizations. The entire situation was acceptably worked out by single manufacturing units, building one or more similar classes of equipment. The problem was solved by developing the inventions of a few engineers. They were intense individualists in mind and methods. They had the ability and were strong enough to make a success in the commercial application of their designs. The present perfection of bulk handling machinery sums up the dominating individualism and clear vision of men like James M. Dodge, Alexander E. Brown, George H. Hulett, C. W. Hunt, Thomas Robins, and others, cast in a similar mold. Each of these individuals apart from the rest followed his personal star in attacking the problem. The activities of others were not his concern. Private interests, too, rather than public necessity were foremost in promoting this development.

In handling miscellaneous freight, the situation is different. Freight movements are complex and diversified. Classifications of goods are of infinite variety. The sizes and weights of packages are almost limitless. No one manufacturer is in a position to offer equipment suitable for the entire cycle of operation. There is some sort of a device on the market for almost every freight handling operation. About two hundred builders make what popularly might be called material handling machinery. Their products may be classified roughly as loaders, conveyors, carriers, tiering machines, hoists, derricks, cranes, tractors, trailers, trucks, elevators, overhead systems, bulk handling equipment and miscellaneous machinery. A modern freight terminal might readily include equipment from almost all of the classifications just named.

No one manufacturer builds more than a few of these kinds of apparatus. The engineers of one concern are not familiar with the proper application of the specialties of the other groups. For the best results in applying modern machinery to a freight terminal, however, an accurate knowledge of the performance of all the various types of equipment is essential. As the industry is now constituted, such knowledge is not within the province of any designing engineer. It logically falls within the realm of the consulting engineer. There are complicated problems in transportation engineering to be accurately analyzed. Their fundamental relations must be clearly understood.

It is conceded that one of the largest items in moving freight is the cost of handling at transfer points and through terminals. Many authorities claim that this represents the biggest single item of waste in water and inland transportation.

If all this is true why has the adoption of machinery for handling package freight progressed so slowly? Where does the responsibility lie? Looking at the human factors, we see before us:

The Public
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Consulting Engineers

The handling of package freight is a transportation problem. The movement may be by rail, water or other medium. The food we eat and the clothes we wear must be brought from their respective points of origin to the homes of every man or woman. Every time a package is lifted, unloaded or delivered, something is added to the cost of living. Tribute to pay for terminal wastes is levied upon everybody. No individual escapes. The burden is added to the cost of production and the ultimate consumer pays the bill.

Before the war, the Interstate Commerce Commission stated that the railroads of the United States handled over a billion tons of miscellaneous freight annually. Depending on conditions, its handling cost from a few cents up to fifty cents, or more, per ton. In addition, our seaport terminals probably moved more than three hundred million tons of packages. Experts say mechanical appliances could dispose of this tonnage and show a saving of $400,000,000 every year over present charges.

The cost of this waste affects every community and every fireside. The adoption of modern freight handling machinery concerns every man, woman and child. Its adoption is essentially a community problem and involves the welfare of every person. The public, however, consists largely of unorganized individuals. It takes time for the public to wake up. Inertia and lack of interest are responsible for most public inactivity. Modern terminals are necessary for the good of the Nation. The demand for them must finally come from the public.

Labor represents a highly organized and dominating minority. Opposition of labor is sometimes given as a partial reason for inadequate terminal facilities. Instances have been cited where equipment was installed but never allowed to operate. Machinery is said to have been deliberately destroyed by running it off the end of a dock. Opposition of this kind probably arises from fear that something is being put across to lessen a man's earnings or get him out of a job. Where such a fear exists, resistance to change is natural and is as old as the Pentateuch. In the days when labor was plentiful and wages low, freight congestion did not endanger public health. In times, however, of labor scarcity, outlaw strikes and similar upheavals have even shut off the food supply and threatened the welfare of entire communities.

It has been pointed out that one way to stabilize conditions and increase the circulation of goods would be to use more labor conserving machinery. In this manner more men would be available for better paying positions that demand less severe and protracted physical strain. Life insurance companies regard the work of stevedores, dock laborers, longshoremen and railroad freight handlers as hazardous on account of occupation. To cover such cases their age is advanced and the same premium is charged as for a standard risk of the advanced age. The chance of total and permanent disability is greatly increased because of the character of the work. No indemnity benefits, moreover, of any kind, in case of accidents or disability are allowed. Actuaries have decided on the other hand, however, that circus bare-back riders, bookmakers at the racetrack, men handling high voltages in power houses, workmen in fuse factories, professional gamblers or even motor-cycle cops are much better life insurance risks than dock laborers. When a freight handler, though, becomes the operator of an overhead hoist or an electric crane he is considered a desirable and a normal risk.

Facts of this kind in the hands of the public and before enlightened labor leaders are causing the prejudice and opposition to freight handling machinery to crumble and disappear.

The manufacturers of material handling machinery are individualists to a degree. They think largely in terms of their own product and not in terms of the whole industry. Their point of view has been largely developed within the diocese of their own factories. Many still follow the old practice of selling their product on the basis of its assumed excellence, rather than by selling the best method of rendering an economic service, in which their device may be an integral part. They are apt to shy when asked to put down in writing costs per ton for handling different kinds of material. Their catalogs seldom contain reliable or satisfying figures on actual costs of handling or information likely to help a buyer in selecting the most suitable appliance. A searcher for truth of this kind frequently receives nothing more than a confused impression of mystery, solemnity and ignorance.

The public ultimately is going to put across freight handling machinery and get modern terminals on railroads and at seaports. Communities are already interested and hunting for facts. The activities of numerous port commissions and the millions already appropriated are ample evidence. These commissioners, representing states or municipalities, turned first to the manufacturers for help and advice. Many commissioners were disappointed with the result of their investigations. They wanted costs of handling freight using devices considered more or less standard. Most manufacturers, to some extent at least, failed to produce. The trouble was that many of them did not possess the necessary cost information with the facts in convincing shape. The public wants to know what a crane or other machine will do and how much it costs per ton to do it. Most devices, however, are sold f.o.b. factory and performance records are scarce. Manufacturers, too, are more familiar with building than operating their apparatus. Thus far the industry sorely lacks accurate, immediate and reliable records of cost performance. From time to time representatives of the public have put numerous questions to the manufacturers. Questions about individual devices were answered satisfactorily. Answers to questions relating to recommendations for solving a particular problem often indicated lack of appreciation of what other manufacturers had done. Many of the replies confused the investigating commissioners and left them floundering in doubt and perplexity. The manufacturer is not qualified and should not be asked to give engineering service that ought to be rendered only by the consulting engineer.

No manufacturer has had the experience that fits him to solve by himself a problem as broad and as complex as the terminal problem. He must have the co-operation and help of both his fellow manufacturers and the consulting engineer. The manufacturer needs to put more study on what the other fellow has done so he will realize his own limitations. The consulting engineer should become more familiar with the uses of all the different types of handling machinery. The manufacturer must have from the consulting engineer a full statement of the facts and an analysis of traffic movements long before any buildings or structures are designed. The proper assembling and co-ordination of mechanical units are joint responsibilities of both the manufacturer and the consulting engineer. In this latter case, the consulting engineer stands in the relation of trustee to the public.

While the material handling machinery industry, as an industry, is unorganized, it needs only suitable leadership to become a strongly organized minority. The opportunity is here and calls on the industry to cooperate and organize, to render a much needed public service.

Have the manufacturers sufficient vision to look ahead a few years? The public wants their help. The best the manufacturers can do, standing alone, will fall far short of what may be accomplished by getting together as an industry and becoming a part of a well organized minority.

Does the manufacturer see his opportunity or is he merely going to hold hands with the past and believe he is looking into the eyes of the future?

Fundamental Factors of Freight Handling

By D. B. Rushmore

Engineer, Power and Mining Engineering Department, General Electric Company

D. B. Rushmore

THE subject of freight handling comprises the commodities, containers, machinery and devices, carriers, etc., used in transporting goods from one place to another. There is no one subject more deeply interwoven with our complex economic activities.

We start with two fundamental considerations:—the raw materials of nature as found already located and the demand of the human race for goods with an entirely different distribution factor. From the first to the second at every stage goods have to be moved in some form and in some direction until ultimate consumption occurs.

The quality and cost of the service rendered is becoming of increasing importance; also the capacities and limitations of our facilities for this work are exerting influences which are being felt in many other fields.

The general subject of freight handling has become an important and distinct field of engineering activity. To outline the basic fundamental factors which are involved is the object of this paper. The primary motive force involved in the economic activities of the world originates with the demands of individual human beings for goods or service in exchange for which they are willing to give mental or physical labor. Most of the demands of the human race can be classified under the following headings:

The Necessities, Comforts, and Luxuries of Life

- Weapons, explosives, gases
- Food, stimulants, drugs, tobacco, gum
- Shelter, buildings and equipment, monuments, fences, walls
- Clothing, jewelry, personal ornaments, etc.
- Light
- Heat
- Power
- Communication
- Publications
- Transportation
- Tools, implements, etc.
- Instruments, measures, etc.
- Machines, appliances, devices
- Amusements
- Recreations, sports
- Containers
- Objects of art
- Toilet articles, soaps, perfumes, washing powders, etc.

The starting point of the supplying of these human demands are the raw materials of nature.

The Raw Materials of Nature

- Animal
- Vegetable
- Mineral
  - Air—Atmosphere
  - Earth—Surface and sub-surface
  - Water—Ocean and fresh

Animal Kingdom

- Simple organisms, microscopic and single celled
- Sponges
- Jelly fishes, hydroids, sea anemones, coral animals, etc.
- Worms, leeches, etc.
- Animals with spiny skins like starfishes, sea urchins, sea cucumbers, etc.
- Articulated animals with jointed limbs, such as spiders, insects, crabs, lobsters, crayfish, barnacles, water fleas, sand hoppers, etc.
- Mollusca, snails, oysters, clams, cuttlefish, slugs, mussels
- Vertebrata:
  - a. fishes
  - b. amphibia
  - c. reptiles
  - d. birds
  - e. mammals

Vegetable Kingdom

- Mosses, of little or no economic value
- Ferns
- Cereals—ex. wheat, corn, buckwheat, rye, millet, barley, oats, rice
- Forage Plants
  - a. grasses
  - b. legumes—ex. clover, alfalfa, cow-peas
- Fiber plants, ex. cotton, flax, hemp, jute

Vegetables
- a. Tubers, ex. potatoes (white), peanuts, Jerusalem artichokes
- b. Roots—ex. radish, turnip, parsnips, beet, salsify, sweet potatoes, carrots
- c. Bulbs—ex. onion, garlic
- d. Leaves—ex. cabbage, celery, lettuce, brussel sprouts, cauliflower, spinach, chard, kale, asparagus
- e. Fruits—tomato, cucumber, pumpkin, squash, melon
- f. Seeds—peas, beans, soy beans

Fruits
- a. Orchard or Tree Fruits
  1. Pome fruits, as apple, pear, quince
  2. Stone fruits, ex. peach, plum, cherry
  3. Citrous fruits, ex. orange, lemon' grape-fruit
  4. Nuts—almond, Brazil, chestnut, cocoanut, hickory, pecan, walnut
- b. Vine fruits, ex. grape
- c. Small fruits, ex. strawberry, raspberry, blackberry, currant, gooseberry
- d. Plant fruits—bananas, plantain

Forests
- a. Soft woods, ex. pine, spruce, cedar, hemlock
- b. Hard woods, ex. oak, walnut, hickory, ash, maple, elm

Mineral Kingdom

Metallic Minerals
- a. Precious Metals
  1. Gold
  2. Silver
  3. Platinum
- b. Metals mainly useful in industry
  1. Iron
  2. Copper
  3. Lead
  4. Zinc
  5. Tin
  6. Magnesium
  7. Mercury
  8. Tungsten

Non-metallic Minerals
- a. Precious Stones
  1. Diamond
  2. Opal
  3. Amethyst
  4. Turquoise
  5. Garnet
  6. Topaz
- b. Abrasives
  1. Diamond
  2. Corundum (emery)
  3. Quartz
  4. Garnet
- c. Food
  1. Rock salt
- d. Inflammables
  1. Sulphur
  2. Graphite
  3. Diamond
- e. Fibrous
  1. Asbestos

Composition of the Atmosphere

Component	Volume (Per Cent)
Nitrogen	77.30
Oxygen	20.80
Argon	0.94
Water vapor	0.92
Carbon dioxide	0.02
Hydrogen	0.01
Neon	0.0012
Helium	0.0004
Krypton, Xenon, Radio-active emanations, Oxides of nitrogen, Ozone	Traces

The available materials in the earth may be said to exist in a rocky crust ten miles thick, the volume of which including the ocean is 1,633,000,000 cubic miles, and the composition of which is given in the following table:

Composition of Known Matter of the Earth

Density of crust		2.5	2.7
Atmosphere	per cent	0.03	0.03
Ocean	per cent	7.08	6.58
Solid crust	per cent	92.89	93.39
		100.00	100.00

The average composition of the solid part of this shell, frequently known as the lithosphere, is given in table on facing page.

Raw Materials, Sources and Products

Animal

Meats: Packing house products, prepared meats, fish meats, poultry and eggs, fertilizers

Hides: Hair, fabrics, hats, felt, fur, leather

Fertilizers

Oils: Greases, lard oil, tallow, lard

Average Composition of the Lithosphere

	Igneous (95 Per Cent)	Shale (4 Per Cent)	Sandstone (0.75 Per Cent)	Limestone (0.25 Per Cent)	Weighted Average
SiO_2	59.83	58.10	78.33	5.19	59.77
Al_2O_3	14.98	15.40	4.77	0.81	14.89
Fe_2O_3	2.65	4.02	1.07	0.54	2.69
FeO	3.46	2.45	0.30	...	3.39
MgO	3.81	2.44	1.16	7.89	3.74
CaO	4.84	3.11	5.50	42.57	4.86
Na_2O	3.36	1.30	0.45	0.05	3.25
K_2O	2.99	3.24	1.31	0.33	2.98
H_2O	1.89	5.00	1.63	0.77	2.02
TiO_2	0.78	0.65	0.25	0.06	0.77
ZrO_2	0.02	...	...	...	0.02
CO_2	0.48	2.63	5.03	41.54	0.70
P_2O_5	0.29	0.17	0.08	0.04	0.28
S	0.11	...	...	0.09	0.10
SO_3	...	0.64	0.07	0.05	0.03
Cl	0.06				0.06
F	0.10				0.09
BaO	0.10	0.05	0.05		0.09
SrO	0.04				0.04
MnO	0.10			0.05	0.09
NiO	0.025				0.025
Cr_2O_3	0.05				0.05
V_2O_3	0.025				0.025
Li_2O	0.01				0.01
C	...	0.80			0.03
	100.000	100.000	100.000	100.000	100.000

Composition of Ocean and Its Salts

Composition of Oceanic Salts		Composition of Ocean	
$NaCl$	77.76	O	85.79
$MgCl_2$	10.88	H	10.67
$MgSO_4$	4.74	Cl	2.07
$CaSO_4$	3.60	Na	1.14
K_2SO_4	2.46	Mg	0.14
$MgBr_2$	0.22	Ca	0.05
$CaCO_3$	0.34	K	0.04
		S	0.09
	100.00	Br	0.008
		C	0.002
			100.000

Raw Materials, Sources and Products (Cont'd)

Sea

Fish: Fresh, preserved, canned, by-products, fertilizer
Vegetable: Seaweed, chemicals, fibers, foods
Animal: Furs, oils, foods, coral, sponges
Crustacea, mollusca

Forest

Logs: Lumber, timber, shingles, lath, ties, poles, paper, veneer, fertilizer
Fuel: Firewood, charcoal
Chemicals: Gums, oils, dyes, drugs, sugar

Farm

Grains: Flour, breakfast foods, feed, liquors (alcoholic)
Fodder
Fruits: Canned, natural dried, dehydrated
Vegetable: Canned, natural, dried, dehydrated
Fibers: Wool, cotton, flax, jute, silk

Mines

Coal: Hard, soft
Ores: Pig metals, metal shapes, chemicals
Chemicals: Fertilizers, drugs, pigments
Fibers: Asbestos

Quarries

Stone: Soapstone, garnet, quartz, corundum slate, marble, granite, building stone
Banks: Clay, gravel, sand, broken stone

Wells

Oil: Fuels, lubricating, paint, medicines
Waters: Table, salt, chemicals, medicinal
Gas: Fuel, illumination

RAILROADS OF THE WORLD

Country	Date	Length of Railways in Miles
Argentina	1918	21,880
Australia	1918	25,308
Austria (not including Czecho-Slovakia)	1914	14,085
Hungary	1914	13,589
Belgium	1914	5,451
Brazil	1917	17,447
Bulgaria	1916	1,824
Canada	1917	38,604
Chile	1918	5,611
China	1920	6,836
Cuba	1916	2,359
Denmark	1918	2,645
Finland	1916	2,527
France	1914	31,958
Czecho-Slovakia	1914	1,654
Germany	1914	39,600
Greece	1913	1,396
Italy	1917	11,891
Japan	1918	7,834
Netherlands	1917	2,113
Norway	1918	2,010
Portugal	1913	1,854
Roumania	1914	2,382
Russia	1916	48,955
Serbia	1914	977
Spain	1917	9,354
Sweden	1917	9,303
Switzerland	1917	3,660
United Kingdom	1916	23,709
British Colonies	1914	8,128
U. S. A.	1916	298,928*

* Includes 32,547 miles of electric railway.

The total length of all the railways of the world has been estimated at approximately 1,585,950 miles.

World's Merchant Tonage, 1919 and 1920*

The total number and gross tonnage of steam and sailing vessels, 100 gross tons and upward, are shown according to flag of tonnage. Ex-enemy tonnage surrendered under the terms of the Treaty of Versailles but not yet allocated, is included in "All other tonnage."

Flag of Tonnage	June 30, 1919		June 30, 1920	
	Vessels	Gross Tons	Vessels	Gross Tons
Italy	858	1,370,097	1,115	2,242,393
Greece	312	323,796	405	530,261
France	1,440	2,233,631	1,758	3,245,194
Uruguay	43	44,499	47	63,837
Spain	576	750,611	749	997,030
Belgium	152	313,276	213	415,112
Japan	1,418	2,325,266	1,940	2,995,878
United States [a]	4,929	13,091,773	5,457	16,049,289
Norway	1,629	1,857,829	1,777	2,219,388
Roumania	35	63,792	39	74,549
Denmark	645	702,436	745	803,411
Cuba	51	47,295	53	53,439
Holland	931	1,591,911	987	1,793,396
Peru	63	79,342	69	88,962
Great Britain [b]	10,105	18,607,875	10,831	20,582,652
Sweden	1,263	992,611	1,297	1,072,925
China	102	132,515	102	142,834
Portugal	227	261,212	249	275,665
Chile	114	101,647	112	103,788
Russia	618	541,005	613	534,547
Brazil	428	512,675	400	497,860
Argentina	215	154,441	198	150,023
Finland	338	180,962	312	166,689
Germany	1,768	3,503,380	1,138	672,671
All other	995	1,135,396	989	1,542,272
Total	29,255	50,919,273	31,595	57,314,065

a Includes Great Lakes and Philippine tonnage.
b Includes Dominions.

CANALS AND INLAND WATERWAYS

Name of Canal or Points Connected	Total Length Miles	Width Ft.	Depth Ft.
Suez	103	108	35
Cronstad—Petrograd	16	...	20½
Manchester—Manchester and Liverpool	35½	120	28
Kiel Canal (Baltic and North Sea)	61	72	36
Elbe and Trave	41	72	10
Hohenzollern Canal (Berlin-Stettin)	136	32–39	9.8
Marseilles—River Rhone	60	82	..
Odense—Denmark	5	..	20
Cape Cod Ship Canal	13	200	25
Erie and Branches	340.4	150	12
Panama Canal	40½	110 locks 300	41

* Source of information: Lloyds Register of Shipping.

PORTS

Name of Port	Year	Entered (Thousands of Tons)	Cleared
New York	1919	15,049	14,275
Hamburg	1913	12,997	13,192
Hongkong-Victoria	1918	8,528	8,404
Gibraltar	1915	7,158	5,553
Shanghai	1918	6,969	7,080
Liverpool	1917	6,509	5,596
Buenos Aires	1915	6,258	5,654
Lisbon	1915	5,595	5,596
Montevideo	1916	5,557	5,549
Singapore	1917	5,412	5,362
Antwerp	1919	5,301	5,200
Rotterdam	1919	5,209	5,207
London	1917	5,092	3,792
Kobe	1918	5,023	5,132
Marseilles	1919	4,496	2,426
Genoa	1916	4,238	4,403
Rio de Janeiro	1918	3,865	3,888
Trieste	1913	3,466	3,460
Yokohama	1918	3,332	3,256
Havana	1918	3,164	3,145
New Orleans	1919	3,141	3,470
Havre	1919	3,138	1,486

Factors Which Make up a Port

Channels; Quays and Piers; Slips; Transit Sheds; Warehouses; Industries; Belt Railroads; Harbor Transportation Facilities; Local Land Transportation Facilities; Railroad Terminals; Freight Handling Machinery; Power Supply; Custom House; Repair Facilities; Police Protection on Land and Water; Fire Protection on Land and Water.

MAXIMUM SIZES OF PIERS AT LANDING PORTS OF THE WORLD

	Width Ft.	Length Ft.
European Ports		
Antwerp (proposed)	1000	4000
Hamburg	550	3000
Marseilles	430	1318
London (Tilbury Docks)	400	1600
Manchester	275	1250
American Ports		
Buenos Aires (proposed)	667	1930
Portland, Oregon	480	1350
Boston	400	1200
Halifax	340	1250
Montreal	300	1250
Philadelphia	300	1200
San Francisco	200	981
Baltimore	200	1450
New York (proposed at Stapleton)		
8 of	125	1300
2 of	130	1300
2 of	209	1300

(From *Scientific American*, May 1, 1920, page 492.)

Classification of Freight Terminals

Railroad: Local station, branch intersection junction of two roads, transfer station

General

Marine with Railroad Connections

Municipal ownership, railroad ownership, corporate ownership, navigation company ownership

Public Carriers

Marine: Deep-sea, coastwise, lake, canal, river, harbor.

Land: Electric surface roads, electric subways, railroads, trucks, drays.

Carriers of Freight

Animal: Man, dog, horse, water buffalo, ox, camel, elephant, llama, mule, donkey.

Vehicle:
- Hand: Wheelbarrow, sled, hand truck, cart
- Animal propelled: Wagon, sleigh, sledge, cart, tote poles
- Power: Electric truck trailers with tractor steam truck, gas truck, trolley car, freight car.

Boat: Rowboat, canoe, sailboat, raft, ship, tow barge, steamboat, steamship

Containers for Package Freight

Crates: Wood, veneer

Hampers: Wood

Boxes: Wood, veneer, fiber board, metal

Barrels: Slack, tight, wood, steel

Drums: Steel

Bags: Cotton, jute

Wrappers: Jute, paper, burlap, cotton

Freight Handling Apparatus

Gravity Devices—Endless Conveyors—Track Devices—Trackless Devices—Cranes—Elevating and Piling Machinery—Portable Hoisting Machinery.

Classification of Freight

Bulk.

Free Flowing: Oil, sand, grain, coal, ore

Non-flowing: Brick, coke, pig metals, lumber, steel

Live Stock: Horses, cattle, sheep, hogs, poultry

Package: Boxes, barrels, bags, crates, bales, bundles, articles, machinery

Physical Characteristics of Package Freight

Size — Weight — Density — Space factor—Stowage factor—Solid, liquid or gaseous—Dangerous or safe—Odorous or non-odorous—Type of container.

Costs

Factors to be taken into consideration in determining the *actual cost* of handling freight:

Direct labor

Indirect labor

Cost of power

Interest on machinery and plant investment

Depreciation, wear and tear, obsolecense and replacement of machinery

Additional factors to be considered in determining the effect of freight handling on the cost of commodities:

Stand-by charges on vessels, cars and trucks; deterioration of freight due to delays; storage and insurance charges; interest on the capital tied up in the freight; interest on capital invested in warehouse and terminal buildings.

Problems in Freight Handling

Determination of—

Most economical and successful container; most economical and successful railroad car and ship; best arrangement of railroad and steamship terminals; correct ratio of transit shed area to berthing space; correct ratio of transit shed area to warehouse capacity; type and quantity of power driven machinery to be used for each particular case.

A Brief Directory of Material Handling Apparatus

By R. H. McLain

Power and Mining Engineering Department, General Electric Company

An executive may read a great deal about the inadequacy and inefficiency of methods for handling materials and realize fully that the enterprise in which he is interested, whether factory, railway terminal, or sea port, is woefully deficient with respect to this important factor. He may firmly resolve to remedy the evil, but will be unable to act until he has made a thorough study of material handling apparatus with the view to selecting that equipment which is best adapted to his own peculiar requirements. This article has been prepared to assist in making the selection. It presents in condensed form descriptions and illustrations of a large number of freight handling devices which are suitable for handling practically all classes of materials through horizontal and vertical motions, over long and short distances.—Editor.

R. H. McLain

THE object of this paper is to present a fairly comprehensive view of the freight handling field from a mechanical standpoint for the purpose of pointing out to laymen the possibilities of economies in freight handling and the probable type of machine to which they may look for these economies. A number of rules for the application of various types of machinery will be stated, but this subject is so broad that it will be impossible to put in sufficient explanatory remarks to make these rules at all rigid. The author recognizes the fact that the various types of machines are continually undergoing changes and developments which expand or modify their field of usefulness, so that no rule as stated can ever be considered as up-to-date. The field is so large and the opportunities for invention and knowledge are so great that it is impossible to give information which is, in any sense, to be co idered final and correct. In solving proble , connected with freight handling work, it is advisable in each case that an expert study the particular application.

No serious effort would be made to defend the rules announced later on in this article against any attack which might be made upon them by a person who has studied some particular situation thoroughly and disagrees with the recommendation.

For the purpose of this article, material will be divided as follows:

DIVISION OF MATERIAL

Bulk material may be divided into free flowing material such as grain, sand, coal, and non-free flowing material such as ore and asphalt.

Liquids such as oils and others not contained in cases.

Package material may be divided into miscellaneous packages and uniform packages. *Miscellaneous packages* may be divided into large packages weighing 300 lb., and up, medium packages weighing 50 to 300 lb., and small packages weighing 50 lb., or less. Miscellaneous packages are intended to mean not only box, bale and bag material, but also pieces of material such as beefs, shovels, chairs, etc. *Uniform packages* of material may also be divided into large, medium and small as regards weight. This covers such material as comes in uniform bags, boxes or barrels, and hence is more readily adapted to specially built and refined machinery. Bunches of bananas would, for instance, be considered in this class.

Fig. 1. This ancient and expensive method of handling packages could be improved by the use of the hand truck or power-operated machinery

Fig. 2. The well-known Stevedore Truck is very economical for short movements, fifty feet or less, but is of questionable economy at greater distances

MACHINERY

Machinery may be divided into three classes, viz.: First, common laborers using their hands or shovels, forks, etc.; second, hand-operated machinery such as wheelbarrows, pushcarts, two-wheel trucks, four-wheel trucks, etc.; third, power-operated machinery. This power-operated machinery can be divided into three classes: first, machinery for hoisting; second, machinery for conveying; and third, machinery for a combination of hoisting and conveying.

Hoisting machinery consists in general of platform elevators of either the stationary type such as are used in buildings, or the movable type for moving around in rooms; bucket or chain elevators, chutes, gravity lowerators, whip hoists of some type or other.

Conveying machinery comprises: pumps with pipe lines, belt or bucket conveyors, gravity roller conveyors, capstans for pulling cars, horse-drawn carts, electric storage battery platform trucks, electric storage battery locomotives either for running on rails or running on roads (sometimes called tractors), gasoline trucks and tractors, steam railway systems, boats.

Hoisting and conveying machinery consists of escalators, incline belt conveyors, high lift

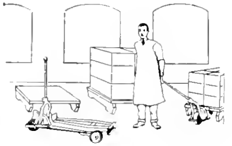


Fig. 3. With a Hand-operated Elevating Platform Truck having skids, one man can lift a load up to 2000 lb. and can move it away. This system is advantageous in factories where the product is piled on skids one small piece at a time and then the whole removed by truck. Skids may also be handled by power machines such as in Fig. 9, and they should be built with this in view

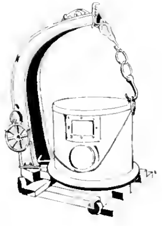


Fig. 4. A Portable Hand-operated Crane useful in a factory or warehouse for making occasional short lifts of heavy pieces which are too large for several men to handle

elevating platform trucks, and especially electric overhead traveling cranes or locomotive cranes; also a combination of several of the types of machinery named under *hoisting* with others named under *conveying* could be used for combined hoisting and conveying.

Cranes cover such a wide variety of machinery that a further detailed description is desirable. Cranes may be divided into two classes, viz., for miscellaneous use, and for

Fig. 5. Portable Power-driven Conveyor set up in sections and used for filling a warehouse with medium size packages. The conveyor can be easily transported to another section of the warehouse for similar duty. The capacity is about one ton per minute

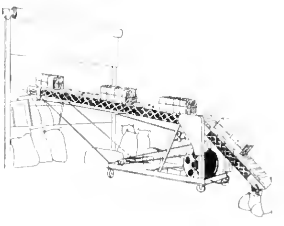


Fig. 6. Small Portable Conveyor used for lifting and transporting medium size packages for a short distance, in connection with loading box cars, wagons, etc. The discharge height is adjustable

special purposes. Cranes for miscellaneous use cover electric overhead traveling cranes, electric cranes with revolving top, and steam, gas, and electric self-propelling locomotive cranes. Special purpose cranes include grab bucket cranes, car dumpers, moving machinery for belt conveyors, magnet or tong cranes, drag line excavators, electric and steam-operated shovels.

PROPER LIMITS FOR MANUAL LABOR

The main object of all machinery is to eliminate manual labor as far as is economical, and to make use of man for the higher purpose of directing the operation of the machinery.

The following rough guide points out the proper places to hope for economies in the use of machinery instead of men, unaided by any mechanical device:

1. Where three or four men are working together on one job for a couple of hours at a time, even though the work is not performed more than three or four times a week.
2. Whenever a man has to lift anything from his feet to a point above his head.
3. Whenever a man has to lift more than 50 lb. from his feet to his shoulders.
4. Whenever a man has to lift more than 100 lb. from his feet to his waist.
5. Whenever a man has to lift more than 150 lb. from his feet to his knees.
6. Whenever a man has to stand in one place steadily moving material for over 30 minutes.
7. Whenever a man has to move material sidewise more than six feet, that is, two steps.
8. Whenever a man or a group of men, although moving around in a small radius, has to move more than 10 tons of material per hour.

If any of these limitations are exceeded there are certainly chances for some kind of machinery to show an economy and to relieve the men of the drudgery of hard labor as illustrated in Fig. 1.

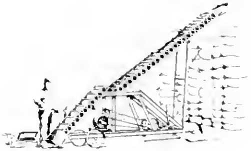


Fig. 7 Portable Conveyor or Motor-driven Tiering Machine The height of the boom is adjustable. Capacity one ton per minute. This device is useful for high piling of bags, bales, boxes, and rolls in a warehouse

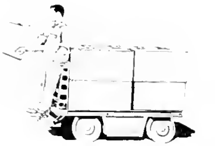


Fig. 8. An Electric Storage Battery Propelled Load-carrying Truck usually geared for about four to five miles per hour, capable of carrying about two tons. This truck is especially suited for handling miscellaneous cargo at steamship and railway terminals; also is adapted for peddling packages of 100 lb. and less in factories or assembly plants where the radius of operation is about 1000 feet. It negotiates narrow aisles and sharp curves

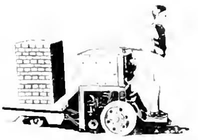


Fig. 9. An Electric Storage Battery Operated Load-carrying Truck, having a platform which is hoisted about three inches by power, is adaptable for use with "dead" skids or with "live" skids on wheels. It can handle one or two tons effectively within a radius of from 75 to 1000 ft., and can be advantageously used in connection with a portable elevator as shown in Fig. 26, so that material can be piled up to about 15 ft. However, it must be used on smooth floors on account of its small wheels, and is adapted for speeds of from three to six miles an hour

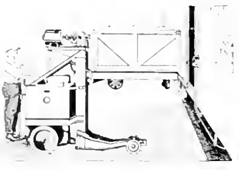


Fig. 10. An Electric Storage Battery Operated Load-carrying Truck similar in principal features to the one shown in Fig. 9 except that the platform with load can be elevated by motor to about 6 ft. 4 in. maximum. It is useful for loading wagons, box cars, serving machine tools, storing material on skids arranged in tiers, and for moderately high piling

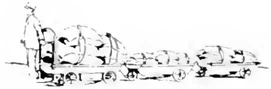


Fig. 11. An Electric Storage Battery Operated Load-carrying Truck, can be used for handling two tons at four or five miles an hour inside a building; manipulates short curves; can, on occasion, be used as here shown for hauling trailers as well. Its best use is for peddling miscellaneous small consignments of about 100 lb. and less within one-quarter mile radius

Fig. 12. Electric Storage Battery Operated Tractor-pulling Trailers. This tractor may be used for pulling anything up to 18 tons at about three to five miles an hour inside a building or between adjacent buildings. It can turn inside a box car; also can pull a train about 100 ft. long weighing 18 tons through narrow and crooked aisles. It is especially useful for peddling consignments of about 500 lb. per trailer within one-half mile radius. A system of this tractor with trailers corresponds to the system in Fig. 3 but it can handle more tonnage a greater distance

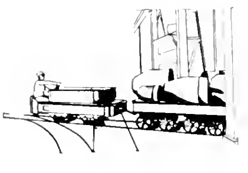


Fig. 13. The Electric Storage Battery Railway Locomotive is especially useful around industrial plants and in some mines. It is adapted for higher speeds, greater tonnage, and greater cruising radius than the trackless electric locomotive shown in Fig. 12. Although it is limited to operation on rails, it requires no trolley wires

SHORT GUIDE TO THE ECONOMICAL USE OF MACHINERY

Once it is decided to eliminate manual labor, the only question is to decide what type of machinery is best adapted for the work and offers the best chances of showing economies. A great deal of business judgment is, of course, necessary in determining what constitutes an economy. In order for a machine to prove its acceptability it must not only show a profit in operation while it is busy but the nature of the installation must be such that the machine can be kept busy a sufficient amount of time to pay an appreciable profit and also to pay for its first cost in a reasonable time. In looking at the problem from this standpoint, all machinery divides itself pretty generally into three classes, viz., portable machinery, self-propelled machinery, and fixed machinery. It is reasonable to suppose that fixed machinery will always operate more efficiently and economically than either of the other classes, provided there is sufficient work at one location for it to keep busy continuously. Portable machinery may be expected to be in general less economical and more fragile than fixed machinery and it can show its best economy where a small amount of work is to be done in one location and a small amount of fairly similar work at another location, and so on. The sum total of work must be sufficient to keep the machine fairly busy and the expense of moving the machinery must be such as to be negligible compared to the amount of labor and expense it saves when it is set up at one location or

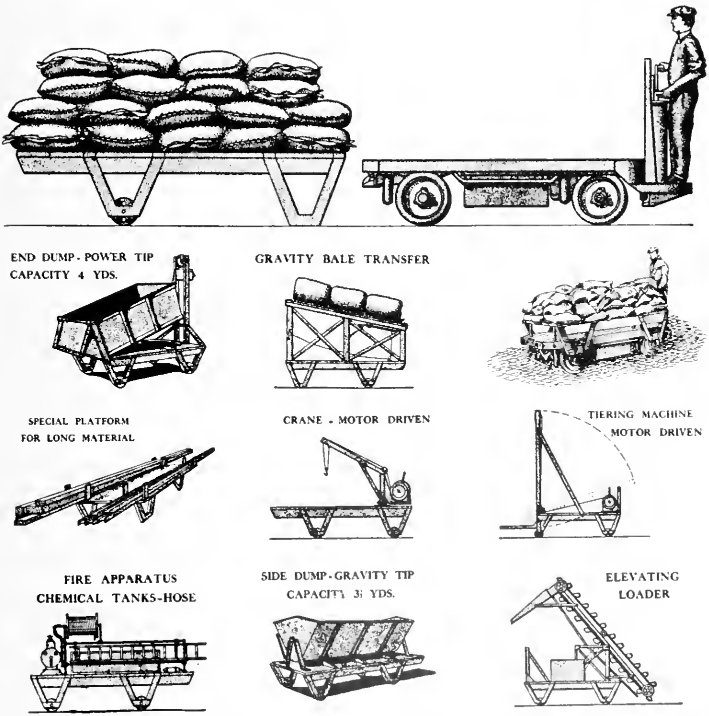


Fig. 16. An Electric Storage Battery Operated Platform-carrying Truck. It weighs 4500 lbs. and elevates 5000 lbs. on a 48 sq. ft. platform through 9½ in. and carries this load at a maximum speed of 7 miles per hour, into box cars or indoors through 6-ft. aisles and on city streets. It is useful for distances between 75 and 5000 ft. for carrying material or machines on any of the platforms shown

another. Self-propelled machinery is generally more expensive than fixed machinery, but for a limited area it has the adaptability of portable machinery combined with the economies and ruggedness of fixed machinery.

The best type of machinery for horizontal, vertical and combined horizontal and vertical movements will next be discussed.

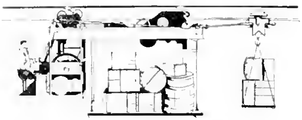


Fig 14. Electrically-operated Monorail Overhead Cranes can be used with a fleet of trailers. Such cranes are especially adapted for lifting and transporting package or bulk goods over difficult topography where aisles are not available on floors, where gorges, roadways, or narrow streams have to to be crossed. Sharp curves can be maneuvered. The speed is approximately seven to ten miles an hour. The tonnage can be made to suit local requirements

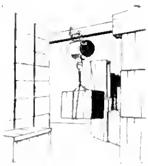


Fig. 15. The Electric Overhead Monorail Hoist is especially adapted for lifting and transporting loads up to about five tons. It is easier to install than an electric overhead traveling crane and can maneuver curves, but, in general, is adapted for light loads only

HORIZONTAL TRANSPORTATION

For Miscellaneous Packages

Man-propelled machinery, such as wheelbarrows, two-wheel stevedore trucks, four-wheel trucks, etc., are generally economical for moving goods up to 75 ft. provided no one package weighs over 1000 lb., and provided the movement must take place between points of receiving and discharge which are not at all fixed. See Figs. 2, 3, and 4.

If the points between which movements take place are fixed for any considerable length of time, medium size packages may be economically handled between distances of 10 and 1000 ft. on belt conveyors if something like 10 tons per hour or more are to be handled long enough to warrant the movement of the machinery up to the points of use. See Figs. 5, 6, and 7.

For movement of material between points which are not fixed for distances ranging from 75 to 200 ft., electric storage battery platform trucks, built for low speed of four miles per hour indoors, are useful. See Figs. 8, 9, 10, and 16.

For distances over 200 ft. and less than 1500 ft., electric storage battery tractors with trailers running at about four or five miles per hour are useful, specially where the movements are to take place between points which are not fixed. See Figs. 11, 12, and 16.

For the same conditions but for points which are fairly nearly fixed, or at least confined to a trackway, an electric overhead monorail crane system with tractors and trailers would be applicable. See Figs. 13, 14, and 15.

For movement of material between 75 ft. and 5000 ft. either indoors, through aisles, or on streets, an electric load-carrying truck which can elevate any one of a system of platforms as shown in Fig. 16 can be used.

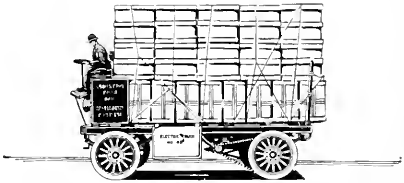


Fig. 17. The Electric Storage Battery Automobile Truck for road use is especially adapted for peddling packages of 200 lb. and less within a radius of about one mile. It has a speed of about 10 miles an hour

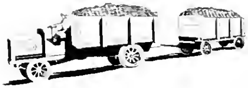


Fig. 18. The Gasoline Automobile Truck and Trailer is the best means for moving loads up to about five tons weight on short haul. This system will probably be expanded to take care of most traffic within a radius of 30 miles

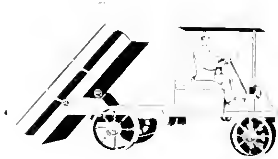


Fig. 19. Gasoline Automobile Truck with special dumping body used for handling free flowing bulk material such as coal, ashes, stone. It reduces the unloading charge to a minimum

For distances between 1500 and 5000 ft., between points which are not fixed, an electric storage battery automobile of the road type, running at something like 8 or 10 miles an hour, would be useful. See Fig. 17.

For distances between 1 mile and 50* miles, where the points of receiving and discharge are not fixed, the gasoline automobile geared for speed between 15 to 25 miles per hour is useful. See Figs. 18 and 19.

For distances between 1 mile and 50 miles, between points which are not fixed, the gasoline tractor with trailers might prove economical. See Figs. 18 and 19.

For distances between 30 miles and say 200 miles, or, if no water transportation is available, any distance, it is probable that the steam railway system affords the most economical transportation. The long distance haulage of material is undergoing radical development. The ideal solution, which is every day approaching realization, is a combination of auto-truck with railway cars. The railway will carry the goods over long distances in demountable unit containers. These will be loaded or unloaded by cranes at terminals on or off auto trucks, and thus distributed and collected locally. Such a system combines the ton-mile economy of the railway with the distribution economy of auto trucks and the handling economy of cranes.

For distances of 150 miles and above, water craft would probably be the most economical means of transportation if conditions are favorable for its operation.

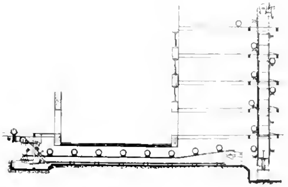


Fig. 20. A Specially Constructed Belt Conveyor suitable for handling barrels between a delivery point adjacent to a warehouse and the floors of the warehouse. All the operations are automatic from the point of delivery until the barrels are rolled away from the carrier. The operation can be reversed to lower the barrels, and the capacity could be made as high as 275 barrels per hour

Of course the proper economic line of demarcation between gasoline trucks, steam railways trains and boats introduces such a large question that no approximations should be allowed to influence a user, and any particular case should be thoroughly studied.

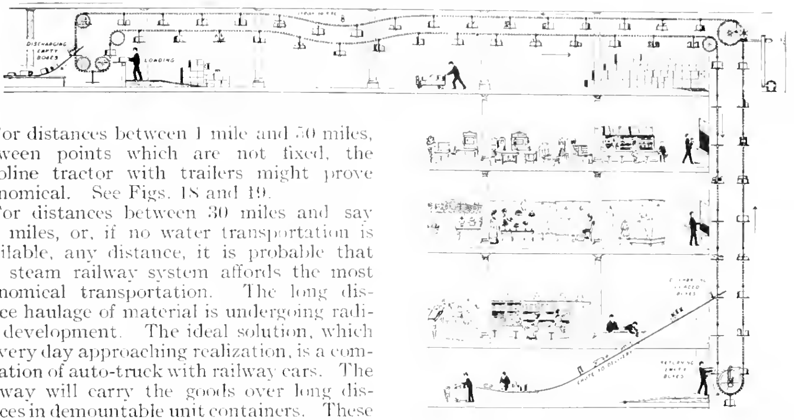


Fig. 21. A Specially Constructed Belt Conveyor for handling selected sizes of miscellaneous packages between a receiving point and store-rooms; also from store-rooms to delivery point in large department stores and mail order houses

For Uniform Packages

Belt conveyors are useful provided tonnage is 10 tons per hour or more between fixed points for long enough time to warrant installation of machinery. See Figs. 5, 6, 7, 20, and 21.

Chutes and roller gravity conveyors are also useful. See Figs 22 and 23.

Of course for distances above 1000 ft., the transportation means outlined for miscellaneous material will apply.

For Bulk Material

Belt conveyors are useful, specially where more than 20 or 30 tons per hour are to be handled between points which are fixed for more than an hour or two. See Fig. 24.

Screw conveyors are applicable to certain material which cannot be moved by belt conveyors.

Free flowing bulk material such as wheat, cotton, straw, etc., may sometimes be transported by pneumatic means.

Trucks with special self-dumping bodies as in Figs. 16, 19 and 25

* This limiting distance is at present uncertain. Roads, traffic, congestion, class of material, price of gasoline and oil are such changing quantities that we can state no final conclusion. 300 miles may be the limit under ideal conditions.

For distances of more than 1000 feet the means outlined for miscellaneous material will apply. Belt conveyors are being considered for carrying coal for five miles out of a mine.

VERTICAL TRANSPORTATION

For Miscellaneous Packages

In the body of a warehouse where stock is not shifted often and where high piling is necessary, the portable platform elevator is useful for packages ranging from 500 to 2000 lb.; but the heavier packages are not handled so economically unless they are of such shape and consistency as to be rolled or moved fairly easily, such as rolls of paper, barrels, etc. See Figs. 26 and 27.

For heavy and unwieldy packages a locomotive crane with a whirler top is likely to be economical, as it affords means of making fast to the material by means of hooks or slings. See Figs. 28, 29, and 30.

Fig. 22. The Gravity Roller Conveyor is very economical where a large number of small packages are to be moved down a slight grade either on a straightaway or around a curve. It is useful in bottling works for handling milk cans, brick, tile, and boxes

Fig. 23. Spiral Gravity Chutes are useful for lowering in warehouses but not for elevating. They have a capacity of about one ton per minute per chute and will handle packages in any size up to 200 lb.

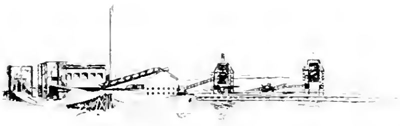


Fig 24 Car Dumper Plant Combined with Belt Conveyor system. This equipment is applicable to loading ships, at right, from railroad cars, dumped at left, by means of rubber belt conveyor at rate of 6000 tons per hour

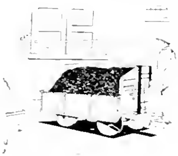


Fig. 25. The Electric Storage Battery Load-carrying Truck, with special body and geared for three or four miles an hour, is especially adapted for running in small aisles around sharp curves and carrying bulk material such as coal, ashes, and crushed stone. It is generally useful in a manufacturing or power plant and can be loaded advantageously by a scoop conveyor such as shown in Fig. 38

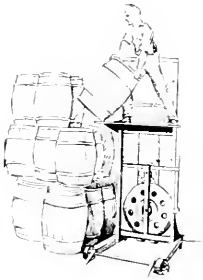


Fig 26. A Portable Elevator enables one man to pile to any height, inside a building, heavy packages which he could not otherwise pile unassisted. As seen in Fig. 27, two men in team work can pile these heavy packages advantageously. The device will handle packages up to about 1500 lb. and will make one trip in about two minutes

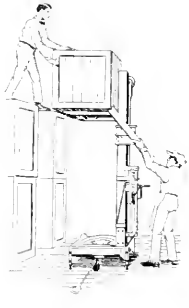


Fig. 27. A variation of Fig. 26 showing the team work of two men. These elevators may be operated by hand crank for low speed or by motor for more rapid speed

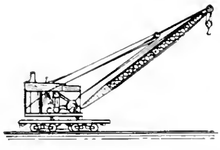


Fig. 28. A Standard-gauge Railway Locomotive Crane may be used for handling rough material such as castings from storage alongside railroad tracks. It can be equipped with a magnet to handle scrap iron, or with a self-filling grab bucket to handle bulk material such as coal ashes, etc., between storage piles and cars or boats. Also, it can be arranged with an especially high boom for placing structural steel in tall buildings, bridges, etc. The crane consists of standard railway power-propelled trucks on which is a revolving jib. The boom can be hoisted or lowered

For small or medium packages inside a building, the portable belt conveyor is adaptable. See Fig. 7.

The electric overhead traveling crane is applicable to this type of work, specially where the material in a certain place is to be moved in and out every day and also where exceptionally large pieces have to be handled. See Figs. 14, 15, and 31.

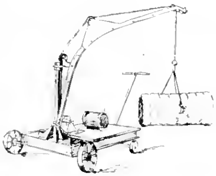


Fig. 29. A simplified Locomotive Crane such as this can be moved around by hand inside a building and used for high piling of heavy and unwieldy packages. A motor is used for hoisting

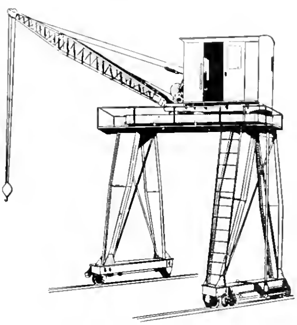


Fig. 30. A Portal Revolving Jib Crane. The jib revolves completely around, the cab moves crossways, and the bridge can move lengthways. Variations of this crane are useful for unloading boats, railroad cars, and handling heavy storage. The useful sizes range from $1\frac{1}{2}$ to 3 tons for ship's cargo. The speed is about $\frac{1}{2}$ to 1 trip per minute. Railroad tracks can be bridged, and the rear can be supported on a building instead of on ground level track

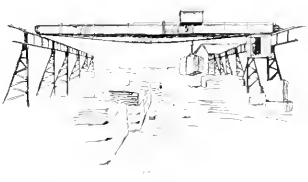


Fig. 31. The Electric Overhead Traveling Crane is especially adapted for handling all size packages at a high rate of speed and especially material weighing over 1000 lb. which men could hardly be expected to move by any other means. It is economical only where a large volume of material is to be moved every day

Between the floors of warehouses, whip hoists attached to a winch, capstan or crane, or to the end of tractor, are applicable if the material is not on wheels, and if hoisting is to be done at one place only.

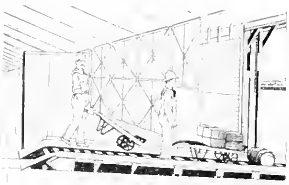


Fig. 32. The Fixed Electrically-driven Ramp is advantageous in overcoming a difference of level due to tide variation. It enables truckers to climb heavy grades without additional labor

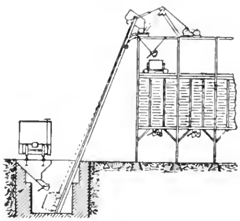


Fig. 33. The Automatic Electric Self-dumping Skip Hoist, can be arranged for carrying material from the bottom of a fixed hopper to the top of another fixed hopper. The heights range from 20 ft. to several hundred feet; and the size of the skips vary from one to twenty-five tons. The number of round trips per hour vary from 30 to 60

Fig. 34. An Electric Overhead Monorail Crane equipped with self-filling grab bucket suitable for carrying bulk material from railway cars or storage piles into buildings. It can manipulate curves and travel at speeds of 7 to 10 miles an hour

If the material to be hoisted between floors of buildings is on wheels, and if arrangements can be made to have a great deal of lifting done at one spot, the fixed platform building elevator and power-driven ramp (see Fig. 32) are available.

For lowering material from upper floor in packages up to 500 lb. in weight a gravity chute or a lowerator is applicable. See Figs. 21 and 23.

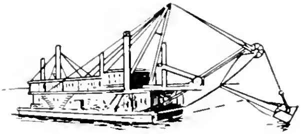


Fig. 35. A Floating Dredge which handles a dipper bucket at the end of a stiff boom is suitable for excavating submerged bulk material. It is used in mining operations and in canal digging or canal clearing

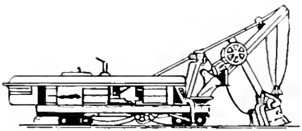


Fig. 36. A Power-operated Shovel carried on standard-gauge railway tracks, is suitable for excavating earth in foundation work, railway construction, and for open pit mining in stone quarries, coal mines, and iron mines. The size of the dipper varies from 5 to 15 tons and the radius of the boom from 20 to 150 ft. This latter requires especially wide-gauge track

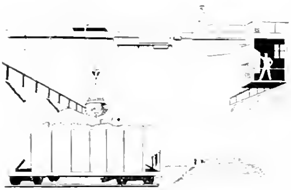


Fig 37. Electric Overhead Traveling Crane similar to that in Fig. 31, used with electro-magnet. This equipment can make one trip a minute for unloading rough magnetic metal, and has the great advantage that it automatically attaches and detaches itself to and from the load by electric means

For Uniform Packages

A belt or chain elevator such as a bucket elevator or barrel hoist is economical where a large amount of work is to be done. See Fig. 20.

Also lowerators and chutes are applicable for this kind of work.

For Bulk Material

Skip hoists are economical where material is to be moved from a hopper to a hopper for capacities from 50 to 1500 tons per hour and where the height or other physical conditions do not lend themselves to the use of a belt conveyor. For limited heights, the belt conveyor is the most economical, specially where a large tonnage, 100 to 2000 tons per hour, is to be moved between fixed points continuously, or for 5 or 6 hours at a time. Such jobs as stowing coal in ocean boats come under this heading. Belt conveyors are limited to not over 20 deg. incline to the horizontal. See Fig. 33.

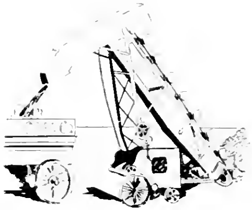


Fig. 38. A Portable Electrically - driven Bucket Conveyor for digging coal out of stock piles and loading it into a wagon or truck. The capacity is about 60 tons an hour

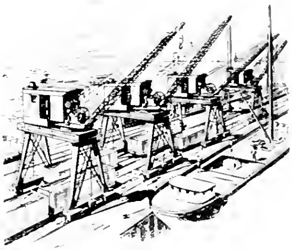


Fig. 39. An Installation of Four Full-portal Gantry Cranes with Revolving Jibs suitable for handling miscellaneous cargo between railroad cars or dock and a ship. The usual maximum load is 6000 lb., but some are built for 10,000 lb.

Grab bucket hoists are useful for large tonnages moved between pile and hopper and are good for any height from 10 to 300 ft. See Figs. 34, 35, 36, and 37.

For lowering material gravity chutes are generally the most economical.

Bucket conveyors are capable of lifting 30 ft. vertically as much as 1500 tons per hour. Smaller sizes can lift 200 tons per hour about 100 ft. See Fig. 38.

COMBINED HORIZONTAL AND VERTICAL MOVEMENTS

For Miscellaneous Packages

Portable belt conveyors are useful provided tonnages are greater than 10 tons per hour and the work is to keep up, between fixed points, long enough to warrant putting the machinery in place. See Figs. 5, 6, and 7.

Systems of tractors and trailers, in connection with platform building elevators, are useful, specially where material is to be distributed over a wide area and provided the loads do not exceed say one ton for every trailer. See Figs. 11, 12, 13, and 16

The electric overhead traveling crane is adaptable for a large amount of work in a small area, where large or unwieldy packages are to be handled. They are well adapted for factory operations. See Fig. 31

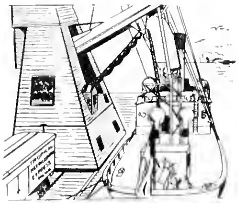


Fig. 40. The Belt Conveyor Type Banana Unloaders, used at New Orleans, do the work of hundreds of men at special terminals used principally for bananas

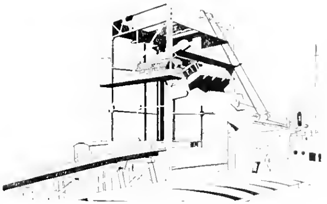


Fig. 41. An Electrically-operated Car Dumper suitable for lifting either one or two standard open-top railway cars, ranging in size from 30 to 100 tons capacity, and spilling the contents over an apron into boats or barges. The range of capacity would be about 600 tons an hour for a small low-speed dumper handling 30-ton cars, up to about 3000 tons an hour for a large dumper handling two 100-ton cars at a time

Monorail cranes are applicable where physical limitations of buildings, topography, etc., eliminate the use of the overhead traveling crane. See Figs. 14 and 15.

Locomotive cranes are useful where the work is of such a nature as to demand an electric overhead traveling crane, but does not continue in one building long enough to warrant the expense of an overhead traveling crane in every building or in every location where work is to be done. See Figs. 10, 28, 30 and 39.

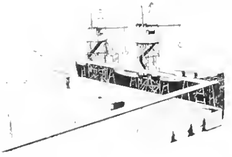


Fig. 42. Coal Tower Hoists unloading coal or bulk material from boats into cableroad which stores it in stock pile. Capacity over 600 tons per hour

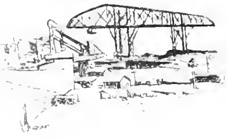


Fig 43. Hulett Unloader for Unloading Ore Boats at rate of 900 tons per hour per machine. It loads ore directly into railroad cars, or into stock pit from which it is put in temporary storage by large overhead grab bucket bridge at rate of about 600 tons per hour

For Uniform Packages

Portable belt conveyors are adaptable for medium size packages provided the tonnage is greater than 10 tons per hour and the machinery can be used long enough to pay for setting it in place. See Figs. 5, 6, and 7.

Special machinery, such as is adaptable for one particular type of package, for instance bunches of bananas or barrels, can be economically designed for handling large quantities of uniform packages. See Figs. 20, 21, 32, 37, and 40

For Bulk Material

Car dumpers are useful for hoisting and dumping railway cars filled with coal, ore or limestone. See Fig. 41.

Special machinery has been designed for dumping wheat out of railway cars.

Belt conveyors have been used for loading wagons at the rate of 10 tons per hour, stowing coal in small boats at the rate of 10 or 20 tons per hour; also for such large jobs as carrying coal 1200 feet and dumping it into ocean-going steamers at the rate of 6000 tons

Kind of Material			Nature of Movement			Machine which is suggested for each class of work is illustrated by the figure numbers given below.
Miscellaneous	Uniform Packages	Small and Medium	Vertical		Tiering	6, 7, 10, 26, 27
					Floor to Floor	Platform Elevator, 5, 20, 21, Whip Hoists, Ramp 32, 23
			Horizontal	Fixed Path	0 to 50 Feet	1, 2, 3, 9, 10, 15, 6, 7 and 22
					50 to 200 Feet	5, 8, 9, 10, 11, 16, 20, 21, 22, 23
					100 to 1000 Feet	8, 11, 12, 13, 14, 16, 20, 21
					1000 to 5000 Feet	13, 16, 17
					1 to 50 Miles	18
					50 or more miles	Automobiles, Railways, Ships
				Wide Area	0 to 50 Feet	1, 2, 3, 9, 10
					50 to 200 Feet	8, 9, 10, 11, 16
					100 to 1000 Feet	8, 11, 12, 16
					1000 to 5000 Feet	16, 17
					1 to 50 Miles	18
					50 or more Miles	Automobiles, Railways, Ships.
			Horizontal and Vertical		Fixed Path	1, 2, 5, 6, 7, 10, 14, 15, 16, 20, 21, 22, 23, (in combination with 22), 26 with 9 or 2, 32, 39, 40, 12 and 13 with Elevators
					Wide Area	1, 2, 10, 12 or 16 with Elevator, 8 or 16 with 26 mounted thereon
		Large	Vertical		Tiering	15, 28, 29, 30, 31, 37 for Iron and Steel Only
					Floor to Floor	Platform Elevators, Whip Hoists
			Horizontal	Fixed Path	0 to 100 Feet	3, 4, 9, 10, 15, 29, 30, 31, 16
					100 to 1000 Feet	13, 15, 28, 30, 31, 16
					1000 to 5000 Feet	13, 16, 17, 28
					1 to 50 Miles	18, Railways
					50 or more Miles	18, Railways, Ships
				Wide Area	0 to 100 Feet	3, 4, 9, 10, 16, 28, 29, 30, 31
					100 to 5000 Feet	16, 17, 18
					1 to 50 Miles	18, Railways
					50 or more Miles	18, Railways, Ships
			Horizontal and Vertical		Fixed Path	14, 15, 28, 30, 31, 39
					Wide Area	4, 14, 15, 28, 29, 30, 31 and 39 may be used for Loading onto 8, 13, 17, 18. Railways and Ships
	Non-Uniform Packages					This non-uniform material can be handled by the same machinery as can uniform except conveyors are sometimes unsuitable for medium and large packages.
Bulk			Horizontal		0 to 20 Feet	38, Inclined Belts similar to 6 and 7
					20 to 5000 Feet	16, 24, 25, 34, 42 Cable Road, Electric Larry Car
					1 to 10 Miles	19, Railways
					10 or more Miles	Railways and Ships
			Vertical		0 to 100 Feet	33, 34, 35, 36, 38, 44, 45, Chutes
					0 to 300 Feet	33, 34
					0 to 5000 Feet	33
			Horizontal and Vertical			24, 28 with Bucket, 34, 41, 42, 43, 46 Electric Larry Car and Platform Elevator.
Liquid not in Cases			Fixed Path		Large Flow	Pipe Lines and Pumps when used a great deal.
					Small Flow	Tanks and 8, 13, 19, 16 when used rarely
			Wide Area			Tanks on 8, 13, 16, 19 and Railways and Ships

Chart Showing Machine or Machines Best Adapted for Handling Materials in Bulk or in Packages Through Horizontal and Vertical Movements per hour. Coal and ore bridges and other grab bucket handling machinery, such as Hulett unloaders, steam or electric shovels, are used most economically in this work. Where conveying distance is to be quite large, these machines are used in combination with a cable-road or auto-electric cars or an industrial steam or electric railway system with hopper cars. See Figs. 24, 38, 42, 43, 44, and 45.

Aerial cableways are adaptable for certain work especially where small-capacity-machinery is to be distributed over a wide area or where unfavorable physical conditions are encountered, such as rivers, gorges, railway tracks. A cableway would not be quite so adaptable for hoisting material say 50 ft. and conveying it 50 ft. as it would for hoisting it 50 ft. and conveying it 1500 ft.; whereas coal and ore bridges are better adapted for hoisting 50 ft. and conveying short distances, 30 to 500 ft., provided sufficient volume of material is at hand. See Fig. 46.

For Liquids

Pumps and pipe lines are used for conveying liquids for any distance where flow is sufficient.

Summarizing Chart

The substance of this short guide to the proper use of material handling machinery has been arranged in the form of a chart, which is shown on page 316.

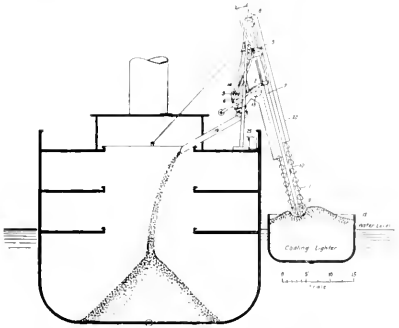


Fig. 44. The Michener Portable Bucket Conveyor arranged for filling the bunkers of an ocean liner with coal from a barge at the rate of approximately 125 tons an hour. On large boats several machines are used simultaneously

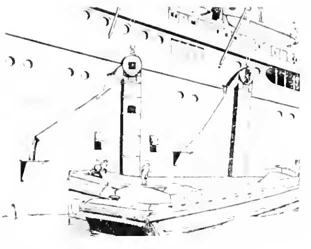


Fig. 45. A View of Two Michener Coal Loaders at Work on an Ocean Liner

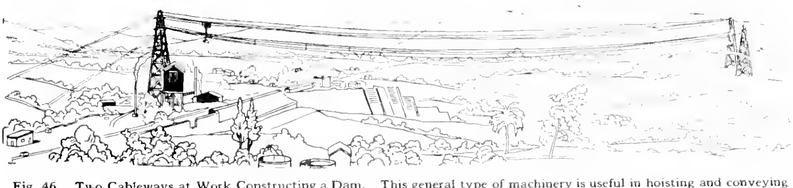
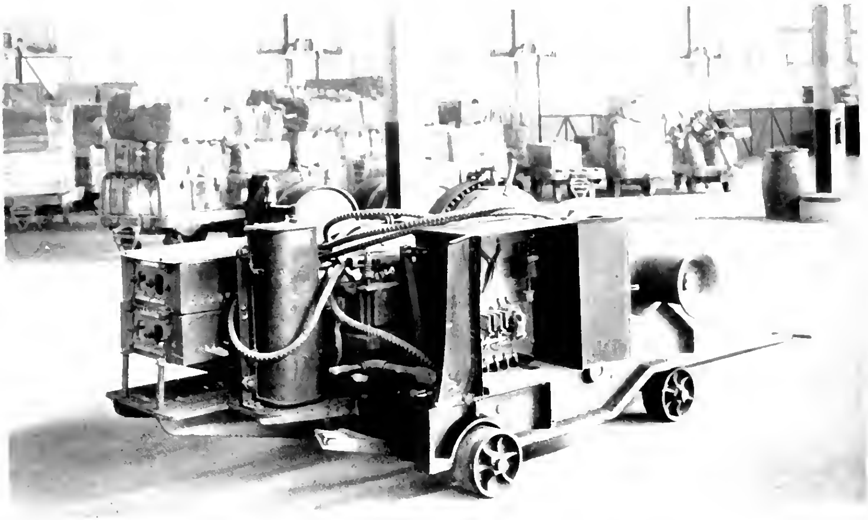
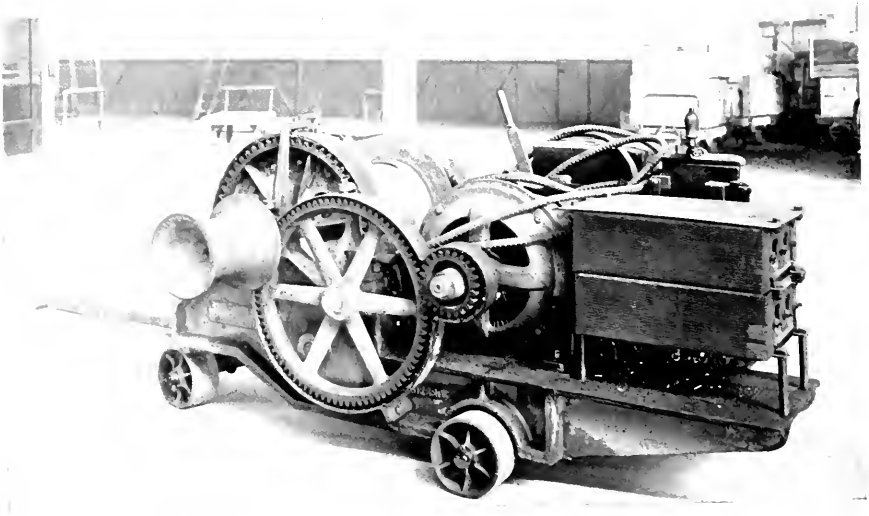


Fig. 46. Two Cableways at Work Constructing a Dam. This general type of machinery is useful in hoisting and conveying building materials in rough construction work in undeveloped country where the topography is of a difficult nature It is suitable for building dams, bridges, aqueducts and locks. It can be arranged so that one or both of the supporting towers move on rails and thus be used for storing bulk material such as coal





Two Views of a Portable Electric Dock Winch Used at the Brooklyn Army Base. The Winch is Driven by a General Electric Alternating-current Motor. Current is Supplied Through a Flexible Cable Attached to a Plug Outlet

Handling of Materials in Industrial Plants

By R. H. Whitehead, M. E.
Of George W. Goethals & Co., 40 Wall Street, New York

The study which has been made of the problem of handling materials in industrial plants has resulted in the development and standardization of a variety of types of labor-saving devices for the purpose. From these a selection can be made to fit almost any ordinary need. Mr. Whitehead divides industrials into power plants, plants employing continuous flow processes, and plants manufacturing and assembling unit parts, and discusses the material handling methods suitable for each. He concludes with a summary of the general principles to be observed.—Editor.

R. H. Whitehead, M. E.

THE purpose of this article is to stress the proper design and equipment of plants with reference to the handling of materials. Many industrial plants that use economical methods for the various manufacturing operations do not give proper consideration to the handling of materials, with the result that production costs are unnecessarily high and maximum output is not obtained. There have been instances where this fact was appreciated at a late date, and as a corrective measure the plants were rearranged and equipped to obtain a better flow of materials with a smaller amount of and less costly handling.

During the last twenty years in particular there has been a large development of labor-saving devices for handling materials by companies manufacturing elevating and conveying machinery, cranes, hoists, industrial railroads, cableways, telphers, power trucks, etc. This development has been of such a nature that standard equipment is available for almost every kind of handling proposition where its use is economical.

In the design of a plant the engineer of broad experience should consult these companies and get the benefit of their detailed knowledge, as in the solution of handling problems the use of standard machinery and equipment is less costly than specially developed machinery, and is not subject to a development hazard. It may be generally stated that the solution of any problem involving handling of materials, if correct, should be a simple one at the present state of the art.

The prevailing general practice to secure the best results is briefly given for a limited number of classes of industrial plants.

Power Plants

The modern central station is generally designed with reference to the proper handling of materials. The use of coal and ash handling equipment has eliminated hand methods, and the uniform flow of fuel coupled with the use of mechanical stokers results in high plant efficiency. These plants use a variety of coal handling equipment also in connection with active and reserve storage, which insures continuous operation. Many of the smaller plants are not laid out to secure the same good results. In some fair-sized plants shovel and wheel-barrow methods are used entirely, although modern coal cars are designed to be unloaded through the bottom doors, and if this is done in a hopper a simple conveyor can be installed to deliver it to a bin adjacent to the boiler-room, where it can be fired by hand. If the plant is large enough to warrant the use of mechanical stokers, the best handling is to break the

Fig. 1. Progressive Assembly Conveyors in Stove Factory. The stoves are handled entirely by conveyors during operations of assembly, enamelling, drying, crating and shipping to platform.

lumps into uniform size by a crusher, elevate them into an overhead bin, and from that point feed by gravity to the stokers. In general it may be said that a medium-size power plant justifies a considerable investment for coal and ash handling equipment.

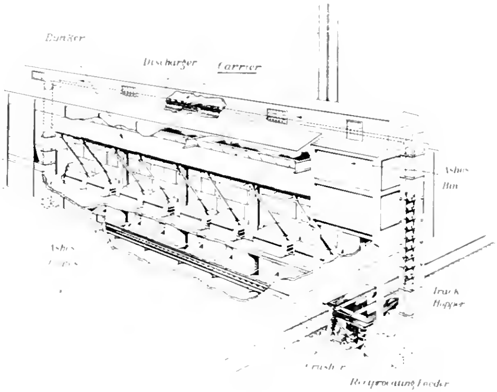


Fig. 2a. Typical Arrangement of Boiler House Equipped with Hopper, Crusher, Carrier and Overhead Coal and Ashes Bin

and more or less of an equipment for reserve storage. In this case, a single carrier can be employed for coal and ashes with an active storage in an overhead bin, and suitable reserve provided outside with handling equipment depending on amount of coal handled in connection with this storage. Frequently it is advisable to handle the coal by a mechanical conveyor and ashes by a steam jet conveyor. In small plants using hand firing a certain amount of coal handling machinery may be a good investment, but little investment is justified for handling equipment for ashes or reserve storage unless conditions are unusual with respect to layout or location. In some plants the equipment provided is far too costly and the investment not warranted. In any power plant the problem is to make the design and the amount of investment suitable for the amount of coal to be handled.

Plants Employing Continuous Flow Processes

In mills employing continuous flow processes there is an increasing tendency to eliminate man-handling of materials and to house equipment compactly to reduce first investment costs and minimize movement of materials. A modern raw sugar mill is a typical case of the large development in this respect. The cane is loaded into cars by cane loaders and weighed. When the loaded car reaches the mill it is tilted by a dumper and the cane discharged into a large hopper, and then conveyed in a continuous stream to the crushers. The bagasse or crushed cane leaving the last set of rolls is conveyed to the furnaces, where it is used for fuel to furnish power for the operation of machinery required and for evaporation of water from the cane juice. After the molasses and sugar crystals are separated out by centrifugals the sugar is automatically conveyed, weighed, and sacked, and the sacks then stacked by conveyors. The use of elevating and conveying machinery, beside eliminating labor, permits of a continuous flow of materials which results in the maximum production for the investment made. The entire equipment is arranged so that the materials flow by gravity in as direct a line as possible from the evaporators to the sacked sugar.

Standard elevating and conveying machinery is available and in wide use in refineries, grain and flour mills, cottonseed mills, cement mills, canning factories, glass works etc.

In modern steel mills, man-handling of materials is practically eliminated, and the car dumpers, ore handling bridges, driven roller tables, cranes with magnets, skip hoists, and industrial railroads for the rapid movement of the large quantities involved, are necessary for low costs of production.

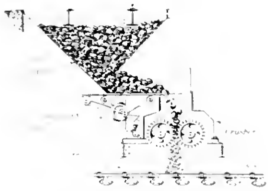


Fig. 2b. Enlarged Section of Fig. 2a.

It may generally be said that the use of elevating and conveying and other handling machinery is particularly advisable in plants employing continuous flow processes, not only from the standpoint of eliminating labor charges but for the purpose of maintaining and regulating volume of production.

Factories Whose Product Consists of Assembled Units

Large factories manufacturing heavy machinery such as steam locomotives, medium weight products such as automobiles, and light weight products such as typewriters, have given a great deal of consideration to the handling problem. In locomotive works where the parts are large and relatively few in number, the handling problem is chiefly one of arrangement and housing of equipment, and overhead traveling cranes, pillar cranes, and industrial railroads to move parts from machine to machine during the manufacturing operations, and to the assembly floor in such a manner that avenues of transportation will be open and the material not only rapidly moved but placed exactly where desired, are employed.

In plants manufacturing such products as automobiles and typewriters, and using quantity production methods, the problem is somewhat different. Plants of this character should show an early uniform output, otherwise inventories will become unbalanced, assembly costs increased, and shipment schedules upset. To assemble at lowest costs, the flow of materials to the assembly department must be uniform, and parts correctly manufactured to avoid delays in fitting. With medium weight equipment, conveying machinery is frequently used on assembly work to set the pace of the plant, and all manufacturing activities are made to synchronize. For instance, in manufacture of automobiles the parts are assembled as the chassis passes each workman on a conveyor traveling at a fixed speed, giving each workman a task to be performed in definite time. In manufacturing typewriters, where the article is small and light, conveyors are not generally used, but the machines are passed along an assembly bench from one workman to another in a continuous stream, and the operations performed are of such a character that each workman is required to do his part in keeping materials moving.

Fig. 4. Continuous Moving Conveyor in Canning Factory

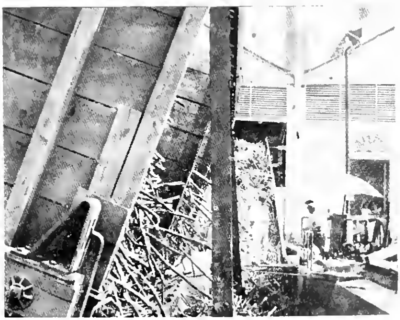


Fig. 3. Cane Being Dumped into Hopper and Conveyed to Crusher in a Modern Cuban Sugar Mill

In the manufacturing of individual parts on quantity production, conveying machinery can be frequently used to advantage to keep a definite amount of work ahead of the skilled machine operator, and to minimize expenditure of effort in getting materials in and out of the machine.

It is realized that while the use of elevating and conveying machinery has numerous possible applications in concerns manufacturing standard products in quantity, the applications for concerns manufacturing a diversity of product are relatively few. Here the problem is to design and arrange the factory and to provide handling equipment that will be generally applicable, and to secure production results by proper organization.

General

Three broad principles may be stated with regard to the proper handling of materials in industrial plants: (1) Handling should be minimized as far as possible. (2) Handling should be considered as an actual step in the manufacturing processes and performed by machinery or otherwise, depending on the economics involved. (3) The best results are obtained where the flow of materials through the plant is as uniform as possible from the raw material to the finished product.

In designing an industrial plant, the various steps of the manufacturing processes should first be studied in detail, the selection of machinery and equipment for the performance of the operations should next be decided on, and the manufacturing units selected and balanced with reference to each other to avoid choke points in production, and then the arrangement, methods of handling materials, and the structure finally decided on. If this is done skillfully and the return from invested capital is carefully considered at all times, then the developed plant should yield the maximum of returns if properly managed. Obviously, every industrial plant is a proposition in itself requiring expert treatment and a detailed knowledge of the business. Among other matters the future of the business must be considered with possible plant expansion. Adequate storage should be provided for, and means for the best handling of materials in and out of storage. The plant should be well located with reference to its supplies and shipments, and economic methods used for handling materials into and out of plants.

Battery Charging for Industrial Trucks and Tractors

By Charles A. Rohr

New York Office, General Electric Company

The fact that industrial trucks and tractors are of immense value for moving package freight in warehouses, transfer stations, piers, etc., is largely due to the unlimited flexibility with which they can be routed, made possible by their independence of any outside source of motive power when in operation. Being storage battery vehicles, however, they require periodic charging. While the equipment for this purpose naturally varies with the number of trucks and tractors, the size and number of their batteries, and the form in which the energy is purchased, the following article on the subject indicates that a motor-generator set with control suitable for charging by the constant-current or series-resistance method is advisable in most cases.—Editor

Charles A. Rohr

PROBABLY no line of apparatus that has been put before the public to facilitate the handling of miscellaneous package freight is more susceptible of general use than the storage battery industrial truck and tractor.

The size of the industrial truck makes it advantageous, from an operating standpoint, to use such a number of cells that some kind of converting apparatus is necessary even where direct current is available from the public utility company.

With the road type of storage battery motor-propelled vehicle, there is room in the battery cradle to install a sufficient number of cells, either of the lead or Edison type, so that ordinary commercial direct-current voltages (115 to 125 volts) may be used without converting apparatus. The number selected is usually 60 Edison cells or 44 lead cells. The first types of industrial trucks put on the market had battery equipment of this kind. Serious operating and maintenance difficulties, due to the smallness of the individual cell which had to be employed because of space, soon caused the truck designer to reduce the number of cells and increase the size of the individual cell.

At the present time, truck and tractor manufacturers use cells of either the lead or Edison type. The number of lead cells is usually 12, 18, or 24, and the number of Edison cells is 24, 30, 36, or 48. Some manufacturers use a different number, but the majority of installations fall in these classes. In addition, the manufacturers of these devices use almost as many different sizes of individual cells as are made by the various battery manufacturing companies.

There have been efforts to at least standardize on the number of cells, but for some reason or other these efforts have always failed. There has never been a valid reason advanced, however, why this should not be done.

In addition to these variations, there is still another complication in the selection of battery charging apparatus, and that is the different kinds of power which the public utility companies offer for sale in various locations. This may be either 115, 230 or 550-volt direct current, or single, two, or three-phase alternating current at almost any voltage. We shall first discuss the charging of industrial trucks or tractors when direct current is available and then when alternating current is available.

While there has been considerable discussion as to the advisability of charging the batteries of different trucks in series when direct current is available in order to do away with converting apparatus, due to the inflexibility of such an arrangement this system is rarely used even though battery manufacturers claim that their batteries are not injured by this method of charging. When 115 volts direct current is available, a series of batteries of from 30 to 44 lead cells may be charged by use of a rheostat with an equal or greater efficiency than with a motor-generator set. Otherwise it is always economical to use a direct-current to direct-current motor-generator set. For general all-round serviceability, the latter is always advisable.

When alternating current is available it is necessary to use a motor-generator set for converting to direct current. Rotary converters have been tried but have not been generally successful, owing to the variation of the direct-current voltage with line variations, and because of other operating and designing reasons. Mercury arc rectifiers have also been used. It is now almost universally accepted that, all things considered, the motor-generator set is the most suitable device to use.

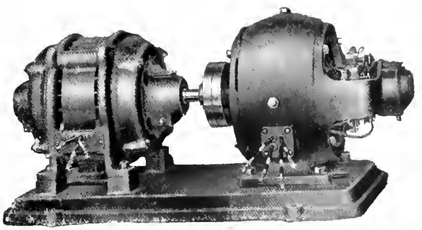


Fig. 1. Battery Charging Motor-generator Set for Use on Alternating-current Circuits

Having obtained the proper direct-current voltage for charging, by the use of converting apparatus, we must consider what to interpose between the battery and charging service for control purposes. The first thing to be provided is a panel for the necessary generator control protection. This is of the standard type used for all kinds of generators and does not need description.

In order to fully charge a battery after discharge, it is necessary to pass through the cells in the proper direction (opposite to that of discharge) an amount of current equal in ampere-hours to that taken out on discharge, plus a certain excess to make up for losses. In general, any charging rate is permissible which does not produce excessive gassing or a cell temperature exceeding 110 deg. F.

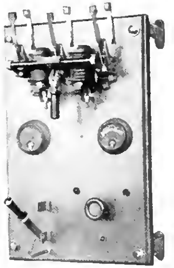


Fig. 2. Automatic Panel for Use with Individual Taper Charging Motor-generator Set

When only one truck or tractor is to be charged, this condition may be approximated by the use of an individual charging motor-generator set in connection with an automatic panel to give the proper taper charge. When more than one is to be charged, it is advisable to charge the batteries in multiple with a control panel for each battery. This is because batteries of different degrees of discharge must be handled.

The most popular method of charging industrial trucks and tractors is known as the constant-current method or series-resistance method, and consists in having a charging rheostat in series with each battery and in holding the charging current constant at the "start" rate until the voltage of the battery has risen to a value of about 2.55 volts per cell (lead battery). The rate is then reduced to the "finish" rate and held constant until the voltage stops rising and the specific gravity becomes constant. If a large variety of batteries having various numbers of cells, such as are encountered in industrial truck installations, are to be used, it is the only method that can be employed.

The ideal arrangement would be simply to plug the battery into a receptacle and when it is charged have the current cut off. This may be done by installing ampere-hour meters on the trucks or charging board, these meters to be equipped with contact points to operate the shunt trip of a circuit breaker.

A well designed control section for each battery should have mounted on it the following equipment:

One charging rheostat (with cast grids on back)
One single-pole underload and shunt trip breaker
One ammeter, voltmeter switch
Two enclosed fuses of proper capacity
One single-pole switch

The instruments are usually mounted on a swinging bracket. It is possible to arrange a more elaborate control on the panel, but for general use the equipment listed is the simplest and best.

Fig. 3. Charging Panel Consisting of Generator Control Section and Four Charging Sections

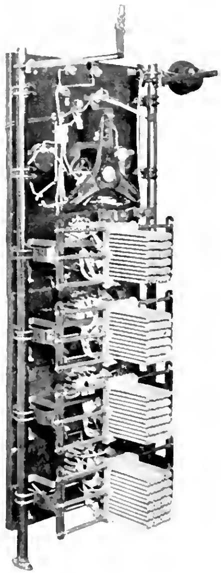


Fig. 4. Back View of Panel Shown in Fig. 3 Illustrating the Method of Mounting Charging Rheostats

The Application of Power-driven Machinery to the Horizontal Transference of Miscellaneous Freight

By J. A. Jackson

Power and Mining Engineering Department, General Electric Company

As the bulk of freight movement takes place in a horizontal plane, and as the application of power machinery to this field is the more difficult on account of the constantly changing routes pursued, this article on the subject is of especial interest. It explains the fundamental principles of routing that must be observed to secure an efficient system for transferring miscellaneous freight or material within a building. The major portion of the article is devoted to a description of conveyors, equipment which runs on tracks, and industrial trucks and tractors with trailers which run directly on the floor. Considerable valuable information concerning the suitability of these various types of equipment and their power requirements is included.—Editor.

The horizontal movement of freight should legitimately be divided into two parts: (1) transportation or the movement by common carriers from terminal to terminal, using "terminal" in its broadest sense; (2) transference, or the movement through the terminals, again using terminal in its broadest sense. Transference, therefore, will include the movement through railroad terminal yards, in railroad and boat terminal buildings, in warehouses and factories, or between buildings of this nature, and also between cars and boats used for the transportation of freight.

In general, freight charges include not only the cost of transportation but a large percentage of the cost of transference as well, and since the cost of transference is out of all proportion to the cost of transportation due to the inefficient methods used, the net result is to make freight charges show up unfavorably, specially on short haul freight where the ratio of transference cost to transportation cost is exceptionally large. This lumping of the costs hides from the public the inefficiency of transference and prevents a crystallization of public opinion to force a change in existing conditions.

A study of the methods of transference is naturally divided into horizontal and vertical motions. Vertical motions are not so complicated to study as the path of such motions is better defined, the weights handled are beyond human endeavor except at extremely low speeds, the necessary calculations for power requirements are easier to make, correct speeds are easier to determine, and sorting and distribution do not enter to so great an extent as in a study of horizontal motions. For these and other reasons the application of mechanical power to vertical motions has progressed more rapidly than its application to horizontal motions.

It is the intention of this article to bring out some of the fundamentals which must be given consideration in the application of mechanical power to the horizontal movement of miscellaneous freight. Bulk freight, such as coal, ore, grain, etc., will not be included in the scope of this article.

Broadly speaking, miscellaneous freight includes raw material, material in the process of manufacture and manufactured material, and in order to cover the subject fully its transference in all these stages must be considered. Since the cost of the horizontal transfer is to a great extent porportional to the distance moved, the first step is to make a thorough study of the lay-out of the building or buildings with the idea of so routing the material that it always travels the shortest distance and in straight lines, if possible. During manufacture it is often quite easy to accomplish this desired straight line movement, as the raw material can be delivered to a receiving department at one end of a building and with a proper arrangement of the machines used for manufacture, it can travel straight through the building and be delivered to the shipping department at the other end.

For a lay-out of this kind, gravity or power conveyors must be given first consideration if the material is of such a nature as to be handled on such devices. The use of metal or fiber trays will frequently be found advantageous for handling small material on conveyors which would otherwise have to be trucked or transferred by hand. The use of such trays makes necessary a conveyor arrangement which will return the empties to their starting point. If conveyors cannot be used, there remains the choice between industrial trucks, tractors and trailers, and the overhead trolley or monorail. With any of these latter devices, the routing of material straight through a building can be improved upon, as such an arrangement necessitates returning empties the length of the building. A better arrangement is to route the material down one side of the building, across the end and back along the other side, having the receiving and shipping departments at the same end of the building. This keeps the freight carriers, whatever they may be, traveling around a loop under load practically all the time. For a new layout a U-shaped building lends itself readily to this method of routing, the carriers running empty across the open end of the U.

If two or more buildings are used, their relative location should be such as to retain as short and straight a path for the material as possible. Where buildings must have two or more stories, the most economical routing becomes more complicated and elevators must be given full consideration. While elevators are vertical machines and hence are outside the scope of this article, their number, location, size of platform and arrangement of platform entrance and egress have such a direct bearing on economical horizontal transference that they cannot be disregarded. This is particularly the case if the product being handled and the layout of buildings are such that industrial trucks or tractors and trailers are to be used. The number of elevators must be sufficient to keep the trucks and trailers moving without congestion at the elevators, and their location must be such as to prevent circuitous routings

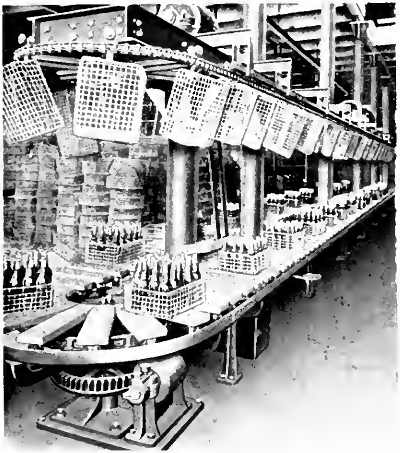


Fig. 1. Motor Driven Horizontal Stationary Conveyors Lower conveyor of the slat type and upper of chain and hook type. Shows containers for adapting the product to conveyor handling. Empties returned on upper conveyor

The size of platform and tonnage capacity will depend on the number of trucks or trailers to be handled on each trip and the arrangement of entrance and egress gates must permit rapid loading and unloading. Gates at each side, so that trucks and tractors may be driven straight through, are desirable for rapid work.

The preceding remarks apply principally to the handling of material in factories during manufacture where the product is somewhat uniform, and little or no sorting or distribution is necessary. At railroad and steamship terminals, however, the problem becomes tremendously more difficult on account of the large number of consignments and the sorting incident thereto. In such places, the utmost flexibility is required and it must be kept uppermost in mind in designing the layout of the plant and in selecting the necessary machinery. The maximum complexity of routing is probably reached in a railroad transfer station for less-than-carload freight, where the number of possible paths for freight increases almost as the square of the number of cars being handled. For example, if there are 200 cars, the number of possible paths is $200 \times 199 = 39800$. Such complexity prohibits the use of fixed machinery, such as conveyors or machinery, running on tracks, thus leaving industrial trucks or tractors and trailers as the only suitable power-driven equipment for this service. The decision as to whether to use industrial trucks or tractors and trailers is determined largely by the size and arrangement of platforms, since tractors and trailers require more room for successful operation than industrial trucks. Further, tractors and trailers are not quite so flexible as industrial trucks, but they have the advantage of reducing the labor and maintenance charges.

On steamship docks and general railroad terminals the problems of distribution and sorting into consignments are important factors, but they are not so serious or complicated as at a transfer station. The reason for this is that freight is being transferred between a large number of consignment piles and a few fixed points, such as the hatches of boats, truck platforms or certain sections of a warehouse. In such cases, fixed routes can often be established for a part of the distance and the distribution be made to start from the ends of these fixed routes. Such a layout favors the use of conveyors on these fixed routes, thereby increasing the overall efficiency, as conveyors are the most economical of all commonly used machines for the horizontal movement of goods.

Ample operating space is absolutely essential for power-driven equipment and aisle spaces should be laid out accordingly. This can best be done by painting the aisle edges on the floor and rigidly enforcing a rule that no piles shall project into the aisle space.

Floor construction requires most careful consideration to secure high economy. Primarily it must be smooth and level and of such a material as to secure good traction under all weather conditions. It must not soften under heat or get slippery from dampness. Good wearing qualities and freedom from warping and cracking are highly desirable features. A rough floor increases maintenance charges, increases power consumption, decreases the life of equipment, makes steering harder, reduces the speed, damages delicate freight, and prevents the heavy loading that is permissible with smooth floors, for which reasons it can readily be seen that inferior flooring is a very poor investment. It is not within the province of this article to recommend any particular type of floor, as each case requires special study. There are several patent floorings on the market which are good.

Machinery for the horizontal transference can be broadly divided into three classes:

1. Conveyors.
2. Equipment running on tracks.
3. Equipment running directly on the floor without rails.

Conveyors are divided into two broad classes, viz., stationary and portable. Stationary conveyors, where applicable, are the most efficient means of moving freight, as the labor, power and maintenance items are extremely low. They are justified, however, only where a large tonnage is to be regularly handled between two fixed points. Thus they are not sufficiently flexible to meet most of the miscellaneous freight problems. Portable conveyors are more flexible and find a broader use, although they are of necessity rather bulky and heavy to handle and set up, for which reason a considerable tonnage must be handled to justify the expense of setting up. Once in use they are as efficient as a stationary conveyor, but operating charges against them are higher than on stationary conveyors due to the labor required for handling and the extra wear and tear caused by moving them around.

With regard to power requirements for conveyors, the horse power to be supplied at the motor terminals for driving a fully loaded horizontal conveyor may be expressed as

$$\frac{W \times K \times S}{33000 \times E \times E'}$$

where

W = Total live load in lb. on the conveyor
K = Coefficient of friction
S = Ft. per minute belt speed
E = Mechanical efficiency of the driving mechanism to motor pinion
E' = Efficiency of motor

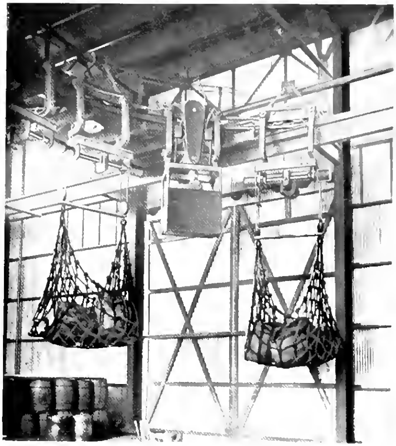


Fig 2 Monorail on Adjustable Loop Tracks Handling Miscellaneous Freight on Steamship Pier

This formula applies only to a completely loaded belt, for with no load on the belt the calculated horse power would be zero; whereas it is a well known fact that the power required to drive an empty conveyor often amounts to from 30 per cent to 60 per cent of the power required when fully loaded, the exact value depending on the design, lubrication, dirt conditions, weather conditions, etc. The value of K varies from 0.09 for a large low speed fixed conveyor for heavy material to about 0.4 for a small portable conveyor. The high value of 0.4 is more in the nature of a factor of safety than as representing the actual friction losses, as portable conveyors are subject to heavy overloads at times. The value of E′ at full load will run from 0.75 on small motors to 0.88

Fig. 3. Industrial Trucks Handling Miscellaneous Freight at Steamship Pier. Each truck contains ten to twelve hand truck loads and no time is lost at the ship's side making up the slings

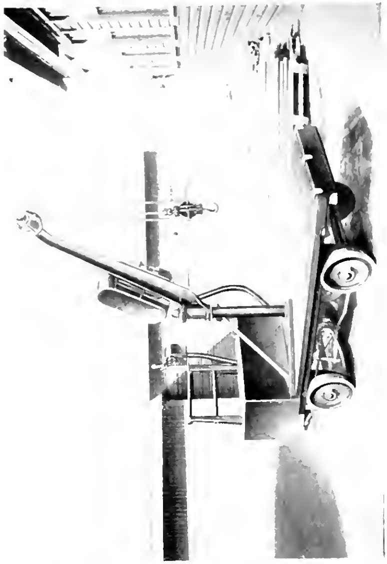


Fig. 4. Motor Driven Industrial Truck with a Loading Crane Operated from a Separate Motor. Crane may also be used for loading trailers drawn up alongside

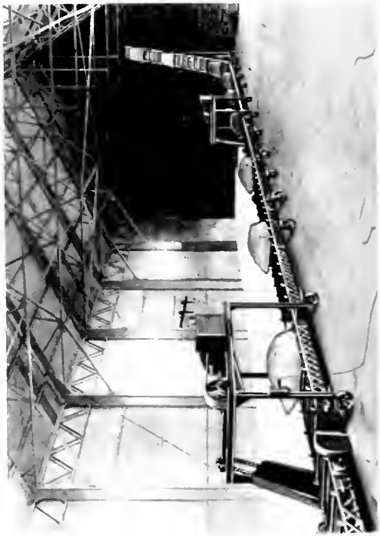


Fig. 5. Motor Driven Horizontal Portable Conveyor. Handling bagged sugar in connection with an inclined conveyor type piler. The introduction of this particular machine cut the labor bill in half

Fig. 6. Tractor and Trailers Handling Small Castings in a Foundry. Note small space required for turning and the boxes on the trailers to facilitate handling small pieces

on large motors. If conveyors are to be run on an incline the necessary addition must be made to the friction horse power to take care of elevating the load.

Equipment running on tracks, such as industrial railways and monorails, are subject to some of the same limitations as are conveyors and find their most useful application where distribution and sorting are not a serious problem and where fairly large quantities of goods are to be transferred between fixed points. They are more flexible than conveyors but have a higher cost of operation due to additional labor and maintenance. Power requirements are very variable and depend on the grade, curvature and condition of track, and the weight of the power unit and trailing load. On a straight level track the horse power required at the motor terminals may be expressed by

$$\frac{T \times F \times S}{33000 \times E \times E'}$$

where

- T = Total load (live and dead) in tons
- F = Rolling friction coefficient in lb. per ton (varies from 10 to 40 depending on track condition)
- S = Speed in ft. per minute
- E = Mechanical efficiency between motor pinion and wheel treads
- E' = Efficiency of motor (0.75 to 0.88 at full load)

If grades are encountered the product of $T \times F$ must be increased by 20 lb. per ton for each per cent grade to determine the horse power required when on the grade.

It is poor economy to stint on the size of the motor because of the number of uncertain factors, such as curves, dirt on tracks, etc.

Equipment running on the floor without rails can be divided into two classes: (1) tractors and trailers, and (2) load carrying trucks, each of which has a broad field of application overlapping in many cases. Tractors and trailers will handle freight at a less cost per ton than industrial trucks, but they lack the extreme flexibility found in the latter. The lower cost is due to the fact that an operator and a helper will handle a tractor with a train of from six to twelve trailers, each carrying from one to two tons or say an average total of $13\frac{1}{2}$ tons, which is $6\frac{3}{4}$ tons per man. The industrial truck, while capable in many cases of handling heavier loads, will probably not average a ton and a half per truck, and an operator is required for each truck and often a helper as well. Further, maintenance is less on tractors and trailers, as the number of power-driven vehicles to be maintained is less for a given tonnage than if trucks are used. Trailer maintenance, of course, has to be included, but it is a small item as compared with the power vehicles. Power consumption for tractors and trains is less per ton (depending on the number of trailers per train), as the dead load per ton of live load is less for tractors and trailers than for industrial trucks. On the other hand, industrial trucks offer the maximum degree of flexibility and can be operated successfully in cramped spaces where tractors and trailers cannot be used. Where consignments are small and there is a large amount of sorting, classification and distribution, the industrial truck is supreme.

Power consumption for tractors and trucks must be looked at from a somewhat different standpoint, since the efficiency of the storage batteries must be taken into account and also the efficiency of the charging apparatus if power is not received in the proper form for charging. The storage battery efficiency (watts input to watts output) varies from about 50 per cent to 70 per cent, depending on the type of battery and the rate of discharge, assuming of course that charging is performed at the correct rate. The efficiency of the charging equipment varies greatly, depending on the kind used, its size and the charging load. For rotating charging sets, such as are generally used, the efficiency varies from 60 per cent to 85 per cent, depending on the size and the amount of load on the set.

The actual horse power required at the motor terminals on a truck or tractor can be expressed by

$$\frac{T \times F \times S}{33000 \times E \times E'}$$

where

- T = Tons total weight (includes power vehicle, live load and tractors if used)
- F = Rolling friction coefficient in lb. per ton
- S = Speed in ft. per minute
- E = Mechanical efficiency from motor pinion to wheel treads
- E' = Efficiency of motor (0.75 to 0.88 full load)

The value of F for general all around service is usually taken at about 50, although it varies between about 28 for hard smooth asphalt to about 300 for a sandy road. The value of F also varies greatly depending on the size of wheels, condition of tires, type of trailer bearings, construction of trailers, maintenance of lubrication, etc., and hence the horse power requirements will vary from day to day on the same vehicle and flooring. Various kinds of road surfaces are given below, listed according to the power required for propelling vehicles on them, and the values of F are approximately correct for each road:

Asphalt, hard	28
Concrete road, smooth	36
Brick, smooth	40
Cement floor	40
Wood blocks	40
Wood planking	43
Brick, glazed	47
Macadam, good condition	47
Granite blocks	56
Brick, poorly laid	57
Gravel or poor macadam	75
Sand road	275

The value of E depends on the design of the power vehicle and the lubrication. On a single reduction worm gear drive designed for fairly high speed, it may reach 0.9 when the vehicle is in the best condition, but 0.7 to 0.8 is undoubtedly nearer the average and still lower values will often apply.

These data show how important it is from a power standpoint to have a smooth floor and to maintain the equipment in the best condition. After determining the horse power it is necessary to divide it by the battery efficiency and by the efficiency of the charging set while the battery was being charged to determine the power consumption per ton handled.

Summarizing the fundamental facts regarding the horizontal transference of freight we have:

1. Economical handling depends very largely on plant layout.
2. The cost of horizontal transference increases with the distance moved.
3. Straight line movement is more economical than curved paths.
4. Ample handling space must be provided to secure economical results.
5. If trackless power vehicles, portable conveyors, or hand trucks are used, floor construction has a direct influence on economy of operation.
6. Fixed machinery such as stationary conveyors show highest economy per ton handled but are least flexible.
7. Individual trackless power vehicles, such as industrial trucks show lowest economy per ton handled but are most flexible.
8. Other forms of machines for horizontal transference fall in between No. 6 and No. 7 in regard to economy and flexibility.
9. Freight handling machinery earns no dividends when idle or running empty, hence keep it moving with loads.

Towers, Cableways, and Skip Hoists in Coal Handling

By C. B. Connely

Power and Mining Engineering Department, General Electric Company

On account of the enormous bulk of coal consumed every year, the problem of handling it economically has resulted in the development of many types of devices each adapted to the sort of conditions prevailing at the place served. The three most prominent of these are described in the following article. Their load characteristics are explained in detail together with the elements necessary for successful operation Interesting figures are given of the power and speeds commonly used.—Editor.

C. B. Connely

That necessity is the mother of invention—a time-worn axiom—has again been proved in the case of coal tower development. Costs, of necessity, have to be at a minimum in handling coal in bulk, and great ingenuity has been shown in the development of devices for unloading coal from vessels and cars.

The development of these coal unloading devices has been along varied lines, owing to local requirements. New England receives the majority of its coal by coastwise transportation and there has been developed what is familiarly known as the Boston steeple tower, with which New England's seaboard is literally studded. This tower consists of an A-frame structure supporting a boom which may or may not be inclined; and suspended from a movable carrier on the boom is a grab bucket.

In its earlier days, the Boston steeple tower was steam operated and originally used two engines, one for hoisting and one for horizontal motion, each requiring an operator. Later the controls of these two motions were combined and one man controlled the bucket.

The modern tower is electrically operated; and with the advent of the electric drive came the convenience and advantages of remote control of the various devices on the tower, which permitted one man control from a centrally located point and resulted in radical changes in the structure of the old original Boston steeple.

Fig. 1 shows the coal unloading tower of the Public Service Corporation at Essex Street, Newark, N. J. It is far removed from the old Boston steeple tower, yet it consists of only a tower forming part of the building. with a properly constructed boom from which the bucket is suspended.

Fig. 2 shows the arrangement of the motors driving the hoist and rack motions. This tower has a hoisting speed of approximately 1250 ft. per min. and makes about two round trips per minute over a hoisting distance of approximately 180 ft. The main hoist motor is direct connected to the hoisting engine and is rated 350 h.p., 200/194 r.p.m. at 440 volts, and hoists a two-ton bucket. The rack motor is rated 75 h.p., 900/865 r.p.m.

Fig. 3 shows a similar tower in use by the Consolidated Gas & Electric Company of Baltimore. Fig. 4 shows the hoisting engine and the racking engine. This tower has a hoisting speed of about 1230 ft. per min. and with a two-ton bucket makes three round trips per minute over a hoisting distance of 115 ft. The hoisting motor is direct-connected to the hoisting engine and is rated 325 h.p., 187/181 r.p.m., and the rack motor is rated 50 h.p., 500/475 r.p.m.

Fig. 5 shows another type of tower and illustrates the variety of motions that can be placed under the control of an operator. This tower revolves around a central leg and in addition has an apron that can be elevated. The photograph clearly shows these features This tower is installed at the Fall River Gas Company, at Fall River, Mass. The hoisting engine is gear driven by a 150 h.p., 720/690 r.p.m. motor and the rack by a 75 h.p., 900/855 r.p.m. motor.

Figs. 6 and 7 show a hammerhead tower coal hoist in the plant of the Labelle Iron Works, Follansbee, W. Va. This tower unloads coal from the river barges and dumps into a belt conveyor which carries the coal directly to the by-products plant, or it can dump into larry cars which convey it to the storage area. Two of these towers are installed on a trackway and coal can be reclaimed from the pile and loaded out. The hoisting speed of these towers is about 600 ft. per min. and not quite two round trips per minute can be made, unloading from the barges or to the conveyor belt.

Fig. 8 shows towers of the North Western Fuel Company at Superior, Wis., and were the first electrically driven coal unloading

Fig. 1 High Speed Coal Tower Essex Station, Public Service Electric Company, Newark, N. J.

towers. Fig. 9 shows two more modern towers erected at this same dock.

Fig. 10 shows the coaling station erected at Cristobal, Panama, by the Isthmian Canal Commission in 1913. This station is notable on account of its immense storage capacity and facilities for rapid handling. These data given in Table I, page 335, are of interest.

The system of operation is as follows:

Coal is hoisted into hoppers by steam towers located at the left of the dock, whence it is carried through chutes into small cars. These cars are electrically propelled at 200 ft. per min. and can carry ten tons of coal. They go around the edge of the dock and dump coal either in a wharf bunker (in the foreground) or into reloading machines at the right of the dock; or they cross the bridges and dump the coal into the storage pile. They go in continuous circuits and are stopped and started wherever desired. The coal is reclaimed from the storage pile by four digging towers, dumped into hoppers at the top of the digging tower, and carried through chutes into the aforementioned small cars. It is transferred in these cars to the wharf bunker or to the reloading towers.

The reloading towers carry the coal on belt conveyors from the hoppers to chutes which spill it into barges.

The photographs show a wide variety of towers, all doing essentially the same thing yet each being designed to meet special conditions. With the exception of the Panama unloading towers, which were ordered in 1912-3 and represent earlier practice, they are all

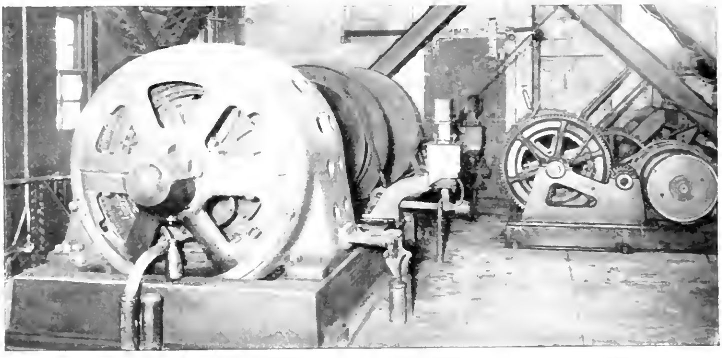


Fig. 2. Hoisting Machinery Essex Station Coal Tower, Public Service Electric Company, Newark, N. J.

electrically operated, this fact indicating the superiority of electric control over all others. Aside from the power equipment, the hoisting engines vary in details, and in the operation of clutches and brakes, etc., according to the ideas of their designers.

The requirements of a motor driving a hoisting engine are: accelerating in the hoisting direction, hoisting, stopping, accelerating in the lowering direction with overhauling load, lowering an overhauling load, and stopping an overhauling load. In this cycle some designers use the friction brake for controlling the load in lowering, while others are using a motor to control the load and return power to the line. In the case of a friction brake, a slightly smaller motor may be used, but with increased wear, maintenance and investment in the friction brake. With a motor controlling the lowered load, a somewhat larger motor is required, but less money is invested in brakes.

With high hoisting speeds, such as 1250 ft. per min., these problems become serious and require expert design to secure adequate control in lowering, either by use of friction brakes or electric motors used as brakes.

It has been found by analysis that the most economical hoisting speeds are approximately:

Height	Speed
50 to 80 ft.	600 ft. per min.
80 to 115 ft.	900 ft. per min.
115 to 150 ft.	1250 ft. per min.

Inasmuch as demurrage charges are generally high and constitute a controlling factor in the cost of handling coal, the coal tower hoist must clean up the vessel in the quickest time possible. This means high rates of acceleration and retardation, which in turn mean

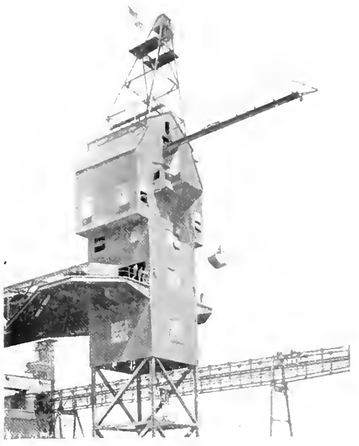


Fig. 3. High Speed Coal Tower, Consolidated Gas, Electric Light and Power Company, Baltimore, Md.

that inertia losses form a big percentage of the total power requirements. It therefore follows that the ideal hoist is a drum direct driven by a motor. Practice has shown that

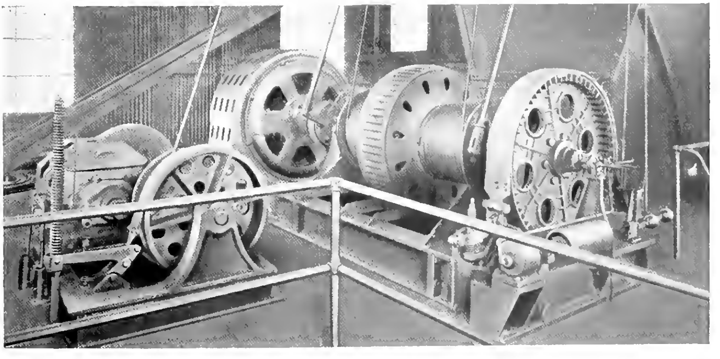


Fig. 4. Hoisting Machinery for Tower Shown in Fig. 3

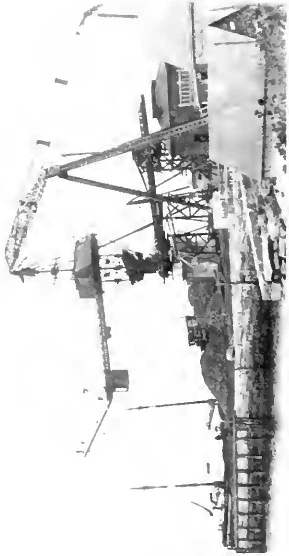


Fig. 5 Radial Handling and Reclaiming Coal Tower, Fall River (Mass.) Gas Works Company

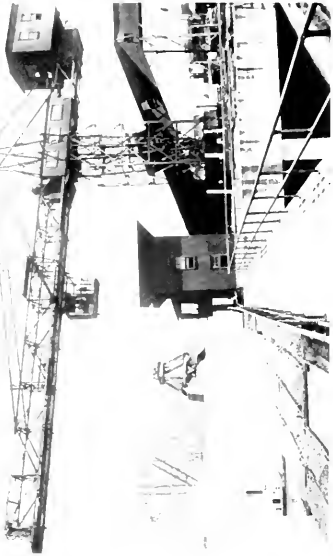


Fig. 6. Hammerhead Tower for Unloading Coal, La Belle Iron Works, Follansbee, W. Va.

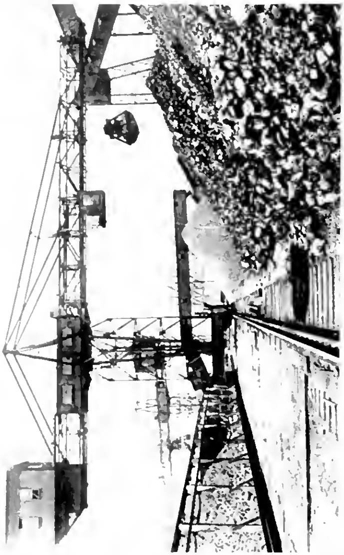


Fig. 7. Hammerhead Crane for Stocking and Reclaiming Coal. La Belle Iron Works, Follansbee, W. Va.

Fig. 8. The First Electrically Driven Coal Unloading Dock Built in 1901, North Western Fuel Company, Superior, Wis.

a minimum diameter of drum for a 2-ton bucket is about 24 ins., and the electrical design does not permit of a motor on 60 cycles at much less than 200 r.p.m., which in turn means a hoisting speed on a 24-in. drum of about 1250 ft. per min. These figures are approximate. On 25 cycles these figures become 125 r.p.m. with a corresponding hoisting speed of about 780 ft. per min. Lower speeds will require gearing.

With the racking distances used on our Atlantic seaboard coal towers, which range all the way from 25 ft. to 50 ft., practice has shown that the best racking speed is approximately 350 to 450 ft. per min., according to distance. This of course means a geared engine. To avoid unnecessary inerita losses, the motor speed should be as low as possible and yet have well designed gearing and proper drum diameter.

The physical ability of the operator to manipulate the controlling apparatus and the mental ability to gauge the speed of the bucket is another limit on the number of trips per minute that can be made, irrespective of hoisting speed or hoisting distance. At the present time, practice would indicate that this is but little over three round trips per minute.

Fig 9 Two Coal Unloading Towers, North Western Fuel Company, Superior, Wis.

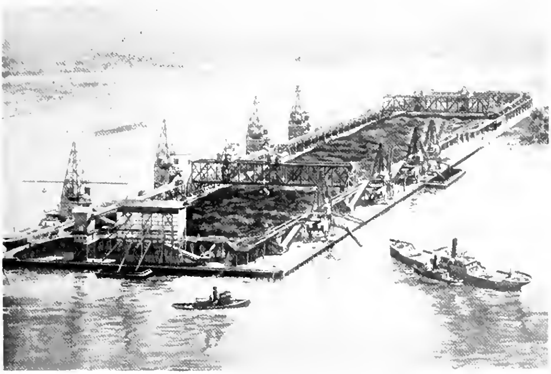


Fig. 10. Cristobal Coaling Station, Panama Canal

The higher speed towers are generally equipped with horizontal booms, but there is another design of tower in which the boom is inclined, sloping down and away from the tower. With this construction, racking or trolley motors are not required; but to avoid dangerous impact the bucket should not be hoisted into the trolley wagon at more than 190 f.p.m. This fact causes a loss of time in

TABLE I

PANAMA CANAL COALING STATION, CRISTOBAL—STORAGE CAPACITY

Coal pile 1700 ft. long by 307 ft. wide by 35 ft above water	385,000 tons dry storage
Coal pile 500 ft. long by 307 ft. wide by 27 ft. deep below water	100,000 tons wet storage
Total ground storage capacity	485,000 tons
Wharf bunker capacity	1,500 tons
Four cargo unloaders (steam), 250 tons each	Capacity 1,000 tons per hour
Two stocking and reclaiming bridges, 315-ft. span, 1000 tons each (electric)	Capacity 2,000 tons per hour
Four reclaiming bridge diggers, 500 tons each (electric)	Capacity 2,000 tons per hour
Four delivery machines, 500 tons each (electric)	Capacity 2,000 tons per hour
28 conveyor cars, 10 tons each (electric)	Capacity 2,000 tons per hour
One wharf bunker (electric)	Capacity 1,500 tons per hour
One viaduct, doubletrack, 29 ft. high, surrounding coal pile	
One transforming and distributing station, 2900 kv-a.	
One administration tower.	
Power supply 440 volts, 3 phase, 25 cycles.	

the cycle, and while the equipment permits the use of less electrical apparatus in that the racking motor is omitted, high speeds cannot be used economically and the towers are limited to slow speed work.

On the Great Lakes, due to the advantageous construction of the vessels, the practice is to use 7 to 10-ton buckets for unloading coal, whereas on the Atlantic seaboard, owing to the fact that coal is received in a variety of vessels, most of which have high keelsons, a smaller bucket has to be used and a 2-ton bucket appears to be the largest size practical.

The cableway is about 1000 ft. long, with the operator's station located approximately in the center. The stationary head tower is 240 ft. high, and the tail tower which is movable is 90 ft. high. The conveying speed is about 1100 ft. per min. with a loaded bucket of 14,900 lb. A 450-h.p. motor operates the tower, and the clutch and friction brakes are electro-pneumatically controlled and operated. This installaton is a very good example of the case with which remote control of hoist apparatus may be arranged, the hoisting engine and control panels being at the foot of

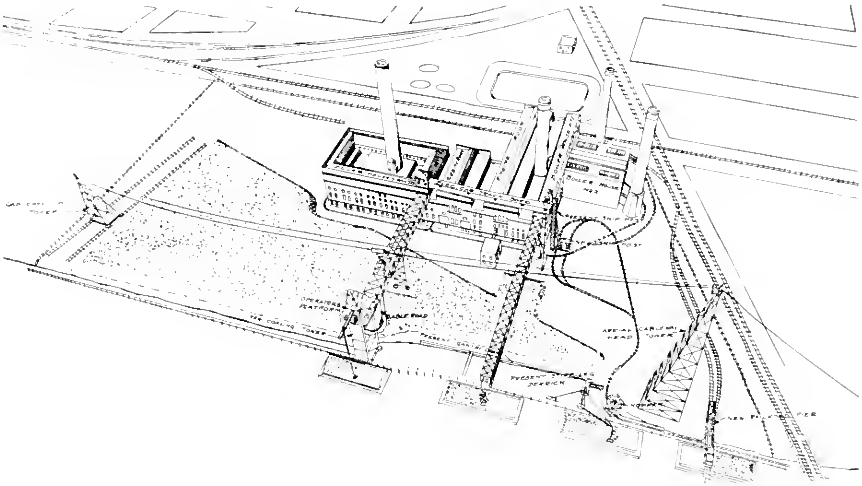


Fig 11. Perspective of Cableway and Coal Storage of the Consolidated Gas, Electric Light and Power Company, Baltimore, Md.

the head tower while the operator's cab is at about the center of the span on the coal tower structure.

With the large buckets the hoisting speed so far has been around 400 ft. per min., which has given sufficient unloading capacity. On the Atlantic coast towers, which have lighter buckets, the speed has been materially higher in order to get the capacity required, and has reached 1250 ft. per min.

Fig. 11 is a perspective view of a cableway and coal tower equipment at the Baltimore Consolidated Gas & Electric Company's Worth Street station, which illustrates excellently the field of usefulness of a cableway. It will be noted that the cableway spans a railroad track, a gantry crane, and a cableroad leading from the coal tower, in addition to serving the coal pile.

Figs. 12 and 13 show the interior of the hoisting house with the driving machinery.

Skips

Skip hoists in the coal handling trade are usually confined to the smaller sizes. They are used largely in railroad locomotive loading plants, and very generally as ash hoists in power stations. A skip hoist generally has to be operated with the maximum of reliability and the minimum of supervision, and is usually in the hands of unskilled labor. A skip, after being loaded, is started by an operator, and modern requirements are such that the skip must hoist, dump, and return automatically and with safety. These problems have all been solved for both direct

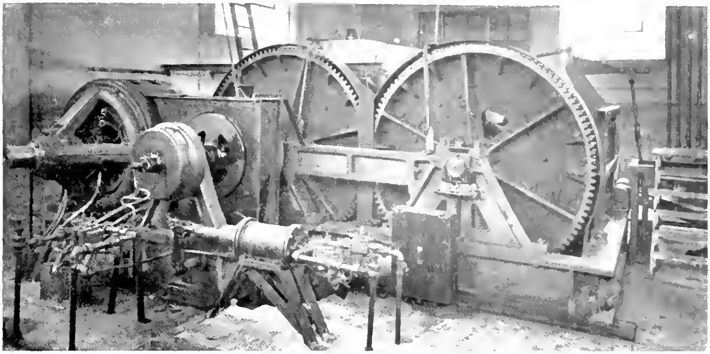


Fig. 12. Machinery House on Cableway Consolidated Gas, Electric Light and Power Company, Baltimore, Md

and alternating-current motors, and skips filling these requirements are in daily operation in innumerable plants. Skips are operated as unbalanced single cars, single cars counter-weighted, and two cars balanced. Hoisting speeds range up to approximately 300 ft. per min. The main problem in the control of skips is the accurate landing of the load. Inasmuch as the final stopping of the load comes on the friction brake, to get accuracy of landing the speed at which the friction brake applies should not be over 50 ft. per min., slowing down from the higher hoisting speeds to 50 ft. being obtained by electric braking. With alternating-current motors this is done by the use of what is known as the two-speed motor; i.e., there is one set of connections or windings for slow speed and another set for high speed, the retardation from high to slow speed being obtained by connecting the motor on the low speed winding and running it as an inductive generator above its synchronous speed during the retardation period.

Late developments would indicate the greater use of squirrel cage motors in skip hoist service. A single-speed squirrel cage motor, if the cycle does not require the motor to be hoisting more than 25 to 30 per cent of the time, should take care of hoisting speeds up to 150 ft. per min.—this in sizes up to 25 h.p., provided the power company permits. Two-speed motors can be built with squirrel cage windings having a ratio of 2:1 or 3:1. With higher ratio a buffer resistance is interposed between the high and low speed winding during retardation, thus limiting the current peaks.

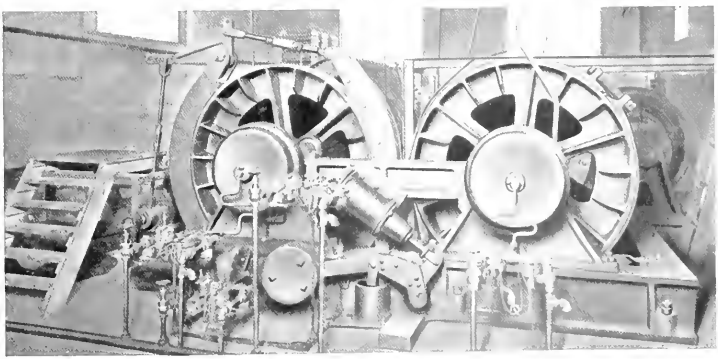


Fig. 13. Hoisting Engine on Cableway Consolidated Gas Electric Light and Power Company, Baltimore, Md.

Conveyors

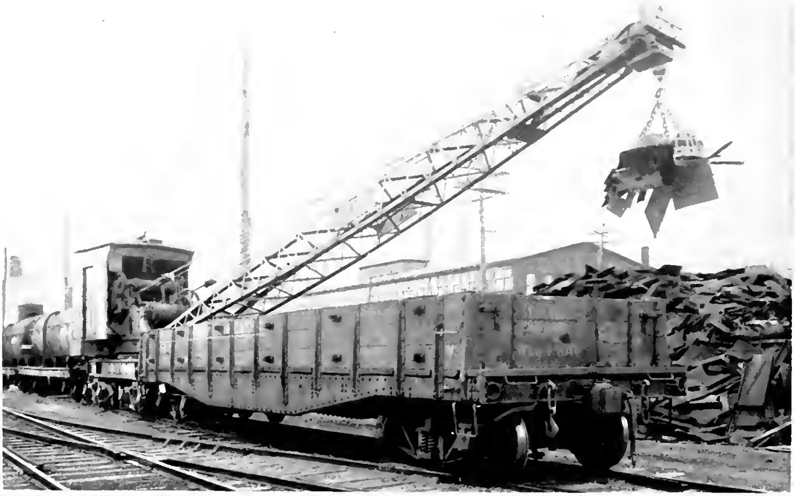
Accuracy of landing or the difference in stopping distance when stopping a loaded bucket and when stopping an empty bucket varies as the square of the speed, the load being the same. It follows then that were the accuracy of landing from a speed of 50 ft. per min. one foot, from 150 ft. per min., it would be nine feet. This clearly shows the need of a low speed from which to make the final step.

While skipways are practically unlimited as to height, bucket elevators for heavy materials are limited owing to internal strains.

Practice has shown that low tonnage elevators, either of belt and bucket or chain and bucket type, can be made light enough so that they can operate up to 150 ft. in height With heavier material, the limiting point seems to be about 125 ft., with the preference of the builders somewhat below these figures. Speeds of bucket elevators range from 100 to 350 ft. per min. depending on the requirements.

For the handling of coke where breakage is a deciding factor, this speed is limited to 50 to 90 f.p.m. With coal the corresponding speeds are higher, ranging from 90 to 130 f.p.m. depending on the breakage allowed. Breakage, however, is due to both discharging speed and distance of fall, both summing up into impact. Speed of discharge is affected by the size of the head pulley in certain cases. With modern stokers small size coal is desirable rather than otherwise, and therefore the breakage due to handling is not the serious question it is in the handling of commercial coal, and speeds of coal elevators for power stations can be materially higher than was considered possible in the past when mechanical stokers were not used. Where no consideration need be shown on account of breakage, the elevating speeds can run up to approximately 160 ft. per min.

The writer will not attempt to make a comparison of hoisting by intermittent duty devices, such as skips or grab buckets with constant speed devices such as bucket elevators, owing to the detail involved in any adequate discussion of belt conveyors.



An Electro-magnetic Crane is Beyond Compare for Handling Scrap Boiler Plate and Structural Shapes Around Industrial Plants and Shipping Yards

Cargo Cranes

By J. A. Jackson

Power and Mining Engineering Department, General Electric Company

In the composition of the following article, the author has described the general construction features of cargo cranes only in so far as they concern his principal endeavor—the explanation of the particular service to which each type of crane is best adapted and the discussion of the effect which various operating conditions have on their design. Such factors as capacity, speed, acceleration, retardation, etc., are treated very thoroughly, and the information and recommendations presented are of great value to the designer and the purchaser. From a careful analysis of the duty required of these types of crane, the author derives the values which must be regarded as the ruling factors in the design of an ideal crane. Editor.

J. A. Jackson

Thanks to the lessons taught us by the great war, the modern mechanically equipped terminal is coming into its own. Although still opposed by a few reactionaries who should know better, its benefits and profits will compel it to win out.

While there is a great variety of electrically driven machinery which is admirably adapted for use on modern piers, one of the most important and popular machines is certain to be the cargo crane in one or other of its forms. The object of this paper is to point out some of the principal features in the design, capacity and speeds of some of the more important types of these cranes, with the hope that the remarks may be of assistance to prospective purchasers when drawing up their specifications.

Considering the design, there are the full arch (Fig. 1) and the half arch (Fig. 2) gantry cranes (often known as the full portal and semi-portal), the various types of roof cranes (Fig. 3, terry roof crane) and the so-called locomotive crane (Fig. 4). Most of these can be still further sub-divided into two classes, depending on the method used for bringing the load from over the hatch to the pier or vice versa. One class uses the swinging jib (Fig. 1) while the other uses a straight line motion, obtained by a trolley wagon running on tracks (Fig. 3) to accomplish the transfer.

The best all-around type of crane to use depends largely on the construction of the pier and annual tonnage handled. For modern piers with a reasonably wide space between the pier shed and the string piece (20 to 40 ft.), the half or full arch gantry would seem the best type, with the half arch gantry somewhat favored since there is no rear leg to interfere with cargo movement on the pier. The only objection to the half arch gantry is that the side of the building must be built sufficiently strong to carry the track for the rear end of the crane. However, as the design is usually such that the rear leg is only lightly loaded, this does not add greatly to the cost of the building. Further, if the pier is a really modern two-story pier with upper landing deck it is likely that very little extra cost will be added to accommodate the rear end crane track.

On modern piers which handle a small annual tonnage, the less expensive locomotive crane finds an economic place, since its tracks may be arranged to switch it to any part of the pier or even into the pier shed if the head room is sufficient. Further, most locomotive cranes are arranged to handle two lines for grab-bucket work, making them useful for handling bulk cargo. Their disadvantages are that they occupy valuable pier space and are not sufficiently flexible to accommodate themselves to extreme variations in height of hatches due to tides and draft; power collective devices, unless costly, are likely to interfere with the horizontal movement of freight on the pier and the operator is not so favorably located for handling his work rapidly as on the higher types of cranes.

The various types of roof cranes are used on piers where there is not sufficient space between the shed and string piece to accommodate the gantry or half gantry types. These cranes have the advantage of being adaptable to obsolete types of piers, provided the substructure and superstructure are strong enough or can be made sufficiently strong to stand their weight. They require openings in the roof of the building which are objectionable in wet or cold weather, and furthermore, unless the hatches of a vessel can be lined up with the openings in the roof

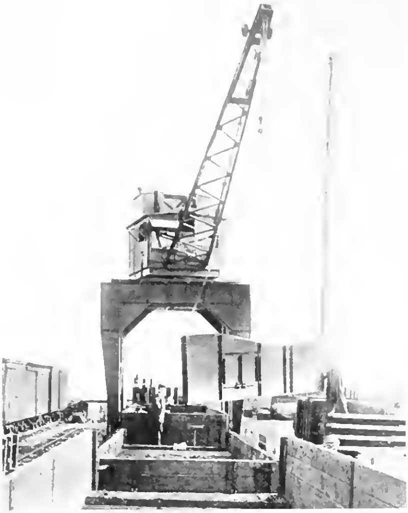


Fig. 1 Full Arch Gantry Revolving Jib Crane Handling Steel Directly from Cars to Lighter

Fig. 2. Half Arch Gantry Revolving Jib Crane on a Quay for Loading and Unloading Ocean Going Ships

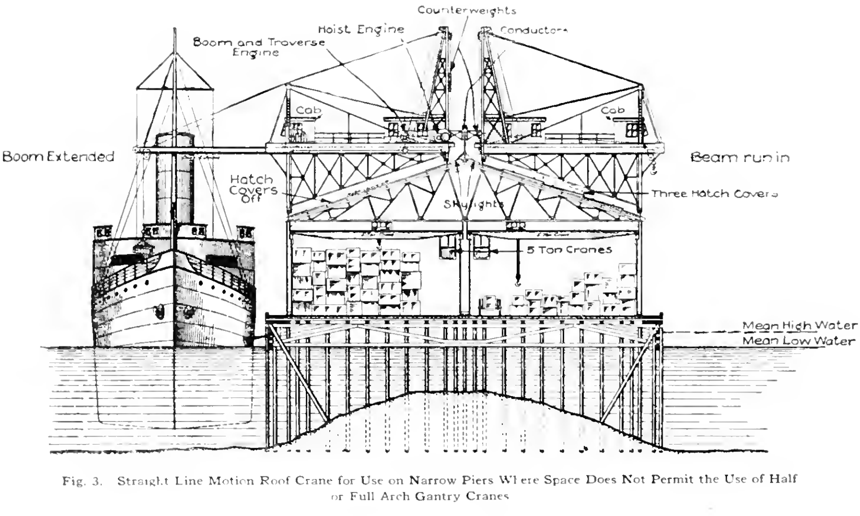


Fig. 3. Straight Line Motion Roof Crane for Use on Narrow Piers Where Space Does Not Permit the Use of Half or Full Arch Gantry Cranes

the crane must be moved longitudinally for each draft which tends to slow up the operation and consume more power.

The relative merits of the revolving jib versus the straight line motion for the transfer of the load between pier and ship have been much discussed and from the number installed both here and abroad the jib crane seems to be the favorite.

Jib cranes have the advantage that two can be easily worked in a single hatch (provided the booms are of sufficient length) by locating them as shown on Fig. 5, while the width of the pier legs of a straight line motion crane may not permit this (see Fig. 6). The trolley tracks of a straight line motion crane can, however, be pivoted in a horizontal plane as shown in Fig. 7, permitting two cranes to be used in a single hatch. Further, two jib cranes can be hooked to a load too heavy for a single crane and by proper co-ordination of their hoist, jib and travel motions, the load can be successfully hoisted, transferred, and lowered. This cannot be done with two straight line motion cranes.

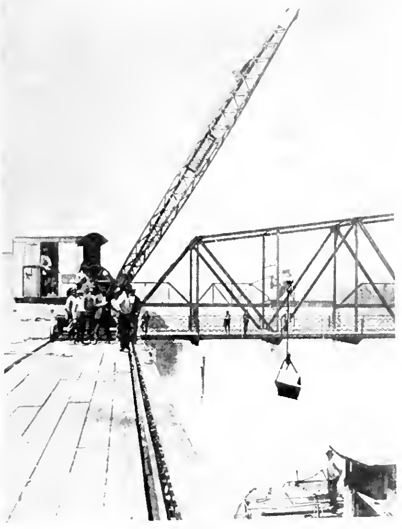


Fig. 4 Electric Locomotive Crane Handling Cargo at a River Terminal

The jib crane on the other hand has the disadvantage of having a large moment of inertia on the swinging motion which requires more power for accelerating and more braking power for stopping. Further, it moves the load in the arc of a circle which requires a greater load speed to convey the load between two points in a given time, which in turn causes more swinging of the load to impair accuracy in landing. Its flexibility, however, seems to outweigh these disadvantages and it is more generally used than the straight line motion crane.

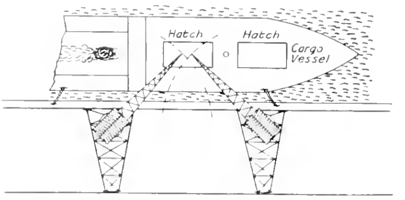


Fig. 5. Plan View Showing Two Revolving Jib Cranes Working in a Single Hatch

Two forms of construction are used in revolving jib cranes, one being known as the pintle type and the other as the turn-table and king-pin type. In the pintle type the weight of the revolving structure is carried on a small bearing of the spherical or roller type, while the over-turning moment is taken care of by two side thrust bearings, spaced well apart to keep down the bearing stresses. The thrust on these two bearings, being in opposite directions, subjects the stationary portion of the crane between them to a severe bending strain requiring a cantilever type of construction. In the turn-table and king-pin types, the revolving part of the crane is carried on wheels which roll on a circular track several feet in diameter. The wheels are held central on this track by a king-pin revolving in a bearing at the center. The disposition of the weights of the revolving structure is such that its center of gravity always falls inside the circular track regardless of the load being handled— within reasonable limits, of course. If correctly designed either type gives good satisfaction, although for a given capacity and speed the turn-table type will usually weigh more, thus requiring more power for accelerating and retarding it.

Turning next to the proper capacity, we find a question on which there seems to be considerable difference of opinion. The capacity should be ample but not one bit more than necessary, as extra capacity means extra weight which in turn means additional first cost and cost of operation. What then, is the correct capacity? A study of a pamphlet entitled "Storage Factors for Ship Cargoes," published by the U. S. Shipping Board in 1919, reveals the fact that out of 2515 commodities, the standard weight of package of 82.6 per cent of them is 500 lb. or less. Between 501 lb. and 2000 lb. the per cent is 14.1 per cent, and between 2001 and 6000 lb. the per cent is 2 per cent. There is 1.3 per cent above 6000 lb., most of which consists of car load shipments of such commodities as lumber, grain, ore, etc.

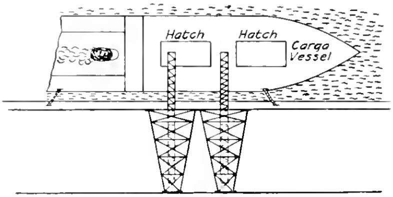


Fig. 6. Plan View of Two Straight Line Motion Fixed Jib Cranes Unable to Work in One Hatch on Account of Interference of Supporting Steel Structure

Due consideration must be given to the fact that many of the 2515 commodities are of such a nature that the quantity handled is small. However, making due allowance for this, the evidence is strong that a very large percentage of general cargo is put up in packages weighing 500 lb. or less.

Of the commodities below 2000 lb. a large percentage of them is of such a nature as to be suitable for making up into sling loads, hence the next question is, what is the average weight of a sling load? One to two thousand pound sling loads seem to work out best for several reasons: first, heavier loads cause the sling to crush the containers and damage the goods in many cases; second, the length of time to make up heavier loads in many classes of goods is such that the crane would have to stand idle while waiting for the load to be made up; third, it seems to be the generally accepted opinion of practical stevedores that the fastest and most economical loading can be accomplished with loads around 1800 to 2000 lb.; fourth, where tractors and trailers are used for handling the goods on the dock, sling loads up to 2000 lb. can frequently be deposited as a unit on a single trailer, where heavier loads must be set down and broken up into suitable trailer loads. From this it seems as though a crane should be designed to economically handle loads up to 2000 to 2500 lb.; but it must also have an overload capacity since it would be uneconomical to have to move a vessel or even the crane and bring up one of greater capacity when greater loads must be handled. Since the per cent of loads above 6000 lb. is so small it would seem best to design for an extreme overload of about 6000 lb.

Direct-current electrical equipment which is designed to handle, without overheating, 2000-lb. loads at hourly tonnage rates usually encountered, will generally have sufficient reserve capacity to handle an occasional 6000-lb. load. Even if a number of 6000-lb. loads must be handled in succession, it is very doubtful whether heating of the electric motor will be the limiting feature, since the fact that the loads are heavy insures their being handled slowly and carefully. This fact automatically prevents any great rise in the tons handled per hour, which is the true measurement of the work on the motor from a heating standpoint. If alternating-current equipment is used, the 6000-lb. load will play a more important part in determining the motor size, since an a-c. motor does not have the overload capacity in torque that a d-c. motor has. This means that for a given capacity crane, an a-c. motor should be larger than a d-c. motor for equal performance.

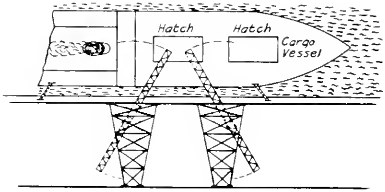


Fig. 7. Plan View of Two Straight Line Motion Pivoted Jib Cranes Working in One Hatch Without Interference of Supporting Steel Structure

For heavier loads, probably the most economical arrangement is to have one heavy capacity floating crane which can be moved about as occasion requires and operated on the outboard side of the vessel without materially interfering with the operation of the smaller dock cranes. Other methods of handling the heavier pieces are to have one heavy capacity dock crane which can be brought up when occasion demands, or two of the smaller cranes can be operated together on a single load. A study of the cranes used on foreign docks where they have had much more experience with such cranes than in this country indicates that 2000-lb. average load and 6000-lb. maximum load is pretty close to the correct capacity.

Now as to speeds: there are always three and sometimes four motions to be considered, viz., hoist, slewing or trolleying, bridging or traveling and sometimes luffing or raising the jib. The speeds of all motions should be so co-ordinated that each speed will in itself work to the best advantage and that the combined speed of the crane will also be the most efficient from every standpoint. For example, the combined speed of a certain crane might be such that theoretically the amount of cargo handled would be just what was required, but this combined speed might be the combination of too slow a hoisting speed and too high a slewing speed, or vice versa, which would result in poor practical operation.

The ideal combined speed of a crane is a speed which causes no delays to either the gangs of stevedores or to the crane itself. Such a speed is impossible of attainment at all times, as operating conditions vary so widely. However, since that part of the cost of handling a ton of freight chargeable against the crane (including fixed charges, power and crane labor) is considerably less than the part of the cost chargeable against stevedores' labor, it is advisable to make the combined speed of the crane high enough to keep just ahead of the stevedores under the worst conditions.

As hoisting and slewing speeds are the most used and hence most important, they will be considered first. The hoisting speed should be considered from the standpoint of the average load to be handled rather than the maximum load which the crane can handle, since it is with average loads that the crane handles most of its tonnage. As to what this average load speed should be, is again a question which does not seem to have been definitely agreed upon. If most of the crane's work is to be in connection with large, deep draft ocean freighters, a higher rope speed is necessary than when used with boats with shallow holds. Tidal range may also influence the rope speed as it may necessitate very high lifts at some stages of the tide, and the rope speed must be high enough to keep all stevedores busy under this condition. The present tendency in all lines of business is to "speed up," and considering the high standby charges against a boat in port it is very essential to speed up the loading and unloading of ships. However, the present rate of handling cargo is limited by the stowing or breaking down of cargo in the ship's hold, but who can tell but what some new method or machine will be developed which will speed up the work in the vessel's hold. Modern cranes should anticipate this and their speed should be selected accordingly. Practical stevedores are likely to advocate relatively low rope speeds first, on account of having been accustomed to niggerhead winches where low rope speeds *must* be used, and second, they have no desire to see anything introduced which will speed up the work. This of course is a wrong attitude, as speeding up by machinery has always benefited labor in the end.

The average load rope speed should, on all but the shortest lifts, be 200 ft. per min. or higher. Many advocates of 225 to 250 ft. per min. can be found, and a few who propose very much higher speeds, up to 400 or 500 ft. per min. It is extremely doubtful whether these high speeds are justified or can be used to advantage even on the highest lifts. Without knowing all conditions, it is not possible to determine the most efficient hoisting speed for any particular crane.

The determination of the correct slewing speed is equally important, and due consideration must be given to four facts:

1. That practically all the work is accelerating and decelerating.
2. That on d-c. supply a series motor is used, making it necessary to take its speed-torque characteristics into consideration.
3. That the average hook load does not play as important a part in determining the speed as it does on the hoist motion, since it is a much smaller part of the total weight to be moved.
4. The pendulum swinging of the load due to centrifugal force increases as the square of the speed.

Lack of appreciation of some or all of these points has probably been the cause for gearing so many cranes higher than necessary. To illustrate some of these facts, Fig. 8 has been prepared showing the accelerating curves of a revolving jib crane with a 35 ft. radius when geared for free running speeds of 2 r.p.m. and 3 r.p.m. It has been assumed that the average swing is 120 deg., which equals a load movement of 73 ft., and of this distance 67 per cent or 49 ft. (80 deg.) is traveled under power and 33 per cent or 24 ft. (40 deg.) coasting and braking, with no power on the motor. The curves are calculated for a d-c. series motor, making full allowance for the effect of its characteristic curve on the acceleration. The accompanying table gives a summary of the calculations which shows the fallacy of gearing for too high a speed.

This table shows that for this particular crane, which represents a typical cargo crane, gearing for 3 r.p.m. and accelerating at 2 ft. per sec. while on the resistor, gains only 0.61 sec. in time, but at an expense of 35 per cent more power, a power peak only 2 per cent less but lasting 143 per cent longer time, a 42 per cent greater swinging of the load and 42 per cent more wear on the brakes than on a similar crane geared for 2 r.p.m. with 3 ft. per sec. acceleration while on the resistor. The increased power consumption for the 3 r.p.m. will in many cases require a larger motor, which means increased first cost, increased power consumption and peaks, and increased overhead and maintenance. Fig. 8 also shows that under none of the three conditions does the crane attain its full geared speed. With 3 r.p.m. gearing it reaches 75 per cent of the full geared speed, while with 2 r.p.m. and 3 ft. per sec. acceleration it reaches 94 per cent of its geared speed at the 49th foot. When geared for 2 r.p.m. and accelerating at 2 ft. per sec. while on the resistor, the time is only 1.1 sec. longer than on the 3 r.p.m. crane, but the power consumption, power peak, and the swinging of the load are much improved. The rate of acceleration while on the resistor can be taken entirely out of the hands of the operator and definitely determined by using magnetic control with current limit acceleration.

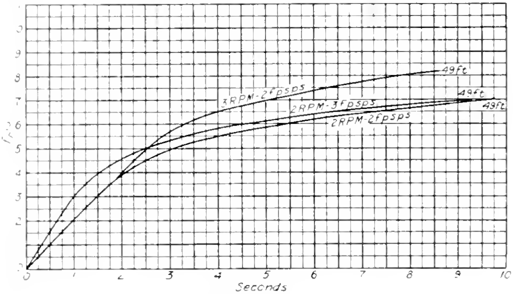


Fig. 8. Acceleration Curves for Different Gearing and Rates of Acceleration on the Slewing Motion of a Revolving Jib Crane

Curve	R.P.M. Geared Speed	Rate of Accel. of Load While on Resistor	Time to Travel 49 Ft. Sec.	Velocity of Load at 49th Foot	Ratio of Load Swing Due to Centrifugal Force	Ratio of Max. Power Peak Drawn from Line	Ratio of Time Max. Power Peak is Taken	Ratio of Total Power Consumption for Traveling 49 Feet	Ratio of Stored Energy to be Dissipated by Friction Brakes in Stopping
1	3	2-FPSPS	8.64 sec.	8.2 FPS	1.42	0.98	2.43	1.35	1.42
2	2	2-FPSPS	9.74 sec.	7 FPS	1.03	0.76	1.79	1.05	1.03
3	2	3-FPSPS	9.25 sec.	6.9 FPS	1.	1.	1.	1.	1.

On a swing of less than 120 deg. the disadvantage of a high geared speed becomes much more pronounced, hence it would seem that cargo cranes (unless with very short booms) should never be geared higher than 2 r.p.m. and that in many cases a careful analysis of the cycle of operation would show that even a slower speed could be used to advantage.

A load hanging from the end of a revolving jib is subjected to two forces which cause it to oscillate like a pendulum when the jib revolves. The first force is caused by the inability of the load to start accelerating at the same rate as the end of the jib due to the flexibility of the rope. This sets up an oscillation which is fairly well under the control of the crane operator, since by skillful retardation he can stop the oscillation before landing the load. The second force is that due to centrifugal force which causes a pendulum swing proportional to the square of the speed at which the crane is revolving. The swing thus produced is very objectionable, since it is beyond the power of the operator to stop it, as it is at right angles to the direction of motion of the load. It is desirable, therefore, to keep it a minimum by keeping down the revolving speed.

The determination of the best speed for the trolley motion of a straight line motion crane is not so difficult to determine, since there is no heavy mass to be accelerated and decelerated and no centrifugal forces acting on the load. The geared speed will depend on the average length of travel, the hourly capacity to be handled, whether the boom is level or inclined, and on the weight of the average load handled. Each case must be analyzed separately and its proper speed determined. Speeds used vary from 200 to 600 f.p.m.

The speed of a luffing motion on a jib crane is relatively unimportant, since the jib is usually placed at the best angle for operation and kept there for relatively long periods of time. It is usually geared for a low speed and the motor must have sufficient power to raise the boom in any position with full load on the hook.

The determination of the correct speed of the bridge motion is in some ways similar to that for the slewing motion, since in each case there is a large mass to accelerate, and, except occasionally, the distance the crane is moved is small. Here again there seems to be a tendency to gear for too high speeds, resulting in costly equipment and inefficient operation. The maximum distance a crane is likely to have to travel is seldom over two or three hundred feet, for if the crane track is longer than this there will very likely be two or more cranes installed. The necessity for traveling the maximum distance generally occurs infrequently and it is not often that there is any necessity for moving the crane with any regularity when handling cargo. If such movement is necessary it is for a few feet only which can be covered more efficiently by a low geared crane with rapid acceleration than by a high geared crane with slow acceleration. Since the duty of the bridge motor is so intermittent, heating usually plays no part in determining its size. It must, however, have torque capacity to propel the crane against the strongest head winds likely to be encountered. With a high geared crane this may call for a large expensive motor even though acceleration under normal conditions is held to a low rate by current limit control. Unless there is some peculiar feature in the regular operation of a crane which requires a lot of bridging over considerable distances, it is questionable whether a speed of more than 100 f.p.m. is justified.

Summing up, a good all-around cargo crane for general work seems to be one which will handle 2000 to 2500-lb. loads at about 225 f.p.m. on a regular loading or unloading cycle. It must be able to handle an occasional overload up to 6000 lb. at whatever speed the motor characteristic gives for this load. The jib should be geared for 2 r.p.m. when handling 2000 to 2500 lb. and the bridge should be geared for 100 f.p.m. The bridge motor must have sufficient torque capacity to propel the bridge at a reduced speed against the heaviest head winds.

Power Distribution for Docks

By Ernest Pragst

Power and Mining Engineering Department, General Electric Company

The character of freight handled at a dock largely determines what types of machinery shall be used to replace old hand labor methods and also the power equipment and distribution system necessary to complete the electrification. The author of this article divides docks into two classes, those handling bulk freight and those handling miscellaneous freight, and then explains the character of the operating load; that is, whether it is continuous and of good load-factor or intermittent and of poor load-factor, and whether maximum overload capacity or heating is the prime consideration in selecting the power equipment. He treats also of such pertinent matters as generated power, purchased power, substation equipment and arrangement, direct-current supply, standard distribution potentials, circuit layout, and protection.—Editor.

Ernest Pragst

As our industrial life and commerce have expanded there has come with it an ever increasing demand for materials and labor. Supplementing this growth and demand, competition has become more and more keen. It has been a healthy state of affairs, for it means progress, leading to economy and efficiency in production and distribution.

Perhaps no one important factor in our commercial life has received more impetus or registered more progress as a result of these economic causes, supplemented by the dire necessities of the war, than the methods of handling ocean freight at our docks.

Only until recent years has it been thought necessary that a dock be anything more than a pier having sufficient depth of water alongside to accommodate vessels visiting the port, and railroad trackage enough to accommodate a few freight cars. In some cases a permanent shelter was built to protect goods from the elements. Freight was handled between the ship's hull and pier deck by the ship's winches; beyond this, in a more or less orderly manner by hand—a rather tedious, slow, inefficient and uneconomical method.

As a result of an ever increasing labor cost and a full realization of the losses involved when vessels lie in port, plus an energetic competition between ports, no effort is now spared to reduce the time and cost of handling freight to a minimum consistent with safety. This means a more careful consideration to the layout and location of the component parts of the dock and the replacement of manual labor by special machines designed for handling freight economically.

With the introduction of freight handling apparatus there comes a power requirement: Energy must be produced or purchased and distributed throughout the dock for the operation of the various pieces of apparatus installed. For obvious reasons this power is invariably in the form of electrical energy, its exact form and quantity depending largely upon the magnitude of the development and the class of freight handled.

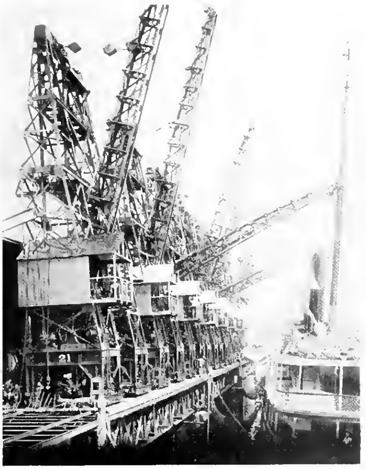
Type of Docks

Generally speaking, docks are divided into two general classes; namely, those devoted to the handling of bulk freight, and those used for miscellaneous package freight. The development and electrification of the former class of dock has received considerable attention for a number of years, while little or no progress has been made in the case of the latter form until within the past few years. The war has thrust upon us a realization of the importance of improved loading facilities, and has been the direct cause and incentive for the recent advancements made in this class of engineering—particularly in the case of those docks devoted to the handling of miscellaneous package freight.

Docks for Handling Bulk Freight

The most representative types of docks devoted to the handling of bulk freight are those specializing in the loading and unloading of such bulk material as coal, ore, limestone, grain, fertilizers and oil. As a rule, this class of dock has but one function, loading or unloading only one kind of material; there is no multiplicity of conditions to be provided for. In the case of such docks—for example, those handling freight from cars to vessels—perhaps the only important variable to be provided for is the variation in size and location of hatches in the vessels to be loaded and in some cases this is overcome by standardizing them.

As docks of this type are designed to handle large quantities of materials at a very rapid rate, the power requirements are comparatively great and of a rather intermittent character. The power load, as a rule, is of two distinct classes, a fairly continuous base load as a result of the input to the continuously operating apparatus — that apparatus which is driven constantly and the load on which is but little affected by the material handled, for example, the various belt drives for conveying and distributing material. Superimposed upon this base load of high load factor is a typical hoist load resulting from the input to the hoist motors which are called upon to lift large masses at high rates of acceleration The characteristic of the hoist loads usually predominates, resulting in a rather jagged combined load curve of low load factor. This means that the apparatus for the generation or conversion of power for the operation of this class of docks must be selected more for its ability to carry momentary overloads than for its heating or continuous rated capacity. Of course, as the number of hoists are increased the load diversity factor is improved, thereby decreasing the importance of overload capacity and increasing that of heating of substation apparatus.



General Cargo Handling Cranes, Balboa Docks, Panama

Docks for Handling Miscellaneous Package Freight

Docks for handling miscellaneous package freight, as the name implies, must be equipped to handle all forms and classes of freight which is not handled in bulk. With the exception of a few docks which have been designed to handle a limited class of package freight, this character of dock must be equipped with a type of apparatus which readily lends itself to the economic handling of packages of the most diversified character.

At docks of this kind the power operated equipment usually consists of:

Cranes
Winches
Storage battery operated vehicles
Conveyors of various types (both stationary and portable)
Piling machines
Fire pumps
Elevators.

To the load imposed by this apparatus should be added that of an effective lighting system, which in some cases is augmented by batteries of searchlights.

It will be noted that the greater part of the handling equipment for this class of dock is of a portable nature. This rather complicates the electrical distribution system, which must be so designed that electrical energy in suitable quantity and form is readily available for the operation of apparatus at all locations where the particular requirements of the time may justify placing it. The tendency in docks of this kind is to handle all freight by means of the dock equipment instead of relying on the ship's winches for raising it as heretofore.

As in the case of docks designed for handling bulk freight, the load is of two characters; namely, a fairly constant one resulting from the demand of the battery charging equipment, conveyors, lights, etc., superimposed upon which is that of the cranes and winches which have hoist characteristics. However, there is often installed a considerable number of these cranes and winches which are relatively low powered. In such cases there is considerable diversity when all of the cranes and winches are working to capacity, and consequently the total load curve is of a more even form and of higher load factor than that obtaining in the average bulk freight handling dock employing a less number of more highly powered hoists. Due to this greater diversity of load in this class of work the generating and conversion apparatus need not have such large momentary overload capacity as in the case of the corresponding apparatus employed at bulk freight docks. As the capacities of the hoisting equipments are increased and their number decreased, the overload capacity of the substation apparatus becomes of greater importance.

Power Generation and Substations

The question as to whether power should be generated or purchased is a purely economic one. Usually it is more economical to purchase central station power; however, it is readily conceivable that in some cases certain local conditions might exist that would make the installation of a generating station both desirable and economical.

Such a generating station presents no particular difficulties in design or operation and need have no special type of apparatus as a result of the class of load served. It need not differ from those usually installed for serving a modern industrial load. It is usually advisable to generate all power in the form of three-phase, 60-cycle, alternating current at a suitable potential (usually 2300 volts), depending upon the distance of transmission and magnitude of load, and convert through either motor-generator sets or synchronous converters the energy for the direct current requirements.

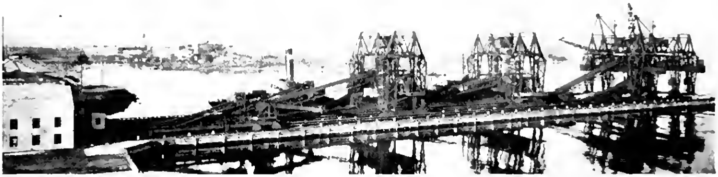
In those cases where power is purchased it is usually received in the form of alternating current at too high a potential for use without transformation, necessitating the erection of a suitable substation for controlling and metering the various circuits, for housing the different transformers and a-c.–d-c. conversion apparatus, etc.

Whether power be generated at the docks or purchased, the power house or substation should be a self-contained structure, so removed from the docks and warehouses that its operation will in no way be interfered with in the case of fire at the docks or warehouses. The whole layout should be such as to assure service to the fire pumps under every possible emergency necessitating their operation.

Substation Arrangement

Assuming a case in which power is purchased, there will be required a central receiving substation. This should consist of a well lighted and ventilated fireproof structure having its main floor well above maximum high water to prevent the possibility of flooding.

The apparatus installed here and the arrangement of connections had better be of as simple a character as possible consistent with the load requirements. Power will be received over one or more circuits. If these are overhead lines, obviously protection against lightning should be provided in connection with each circuit where it enters the substation. Each circuit should be controlled by an oil circuit breaker, care being taken in its selection to see that it is of ample rupturing capacity to safely open any short circuit which it might be called upon to rupture (this, of course, also applies to all other circuit breakers). These incoming line circuit breakers control the power feeding into the substation's high tension bus (a single bus is usually sufficient). The incoming power can be determined by a suitable watthour meter operating from current and potential transformers placed in this high tension bus between the incoming lines and circuits controlling the substation apparatus. Often all incoming power is stepped down from the incoming potential through one or more banks of power transformers to a common low tension bus (usually 2300 volts)



Baltimore & Ohio Railroad Coal Loading Pier, Curtis Bay, Md.

for distribution throughout the property. This is particularly the case in those installations covering large areas where the loads and distances between the central substation and load centers are such as to make it advisable to install the a-c.–d-c. conversion apparatus and low potential transformers near the load centers.

Certain low tension distributing potentials have now become practically standard, namely, 2300 volts, 460 volts, and 230 volts, for a-c. three-phase power circuits; 230/115 volts, three-wire for lighting; and 250/275 volts for d-c. power.

Where the incoming potential is not high and where the distances between the main substations and load centers are short, practically all of the principal pieces of transformation and conversion apparatus are usually placed in the main substation and each operated directly off the high tension bus. For example, in the case of a dock having these characteristics, handling miscellaneous package freight, the following classes of load may be expected:

Cranes	Direct current
Winches	
Storage battery vehicles	
Elevators	
Conveyors	Alternating current
Piling machines	
Lighting	
Fire pumps	

Assuming that central station power is purchased at 11,000 volts: If synchronous converters are used for securing the direct current for the operation of cranes, winches and elevators, their corresponding transformers may be designed for operation from the 11,000-volt bus; or if motor-generator sets are employed, it will probably be desirable, due to the cost of winding relatively small motors for such a potential, to include sufficient additional capacity in the step-down transformers used for supplying the a-c. load to drive the motor-generator sets. In this special case the synchronous converter installation will work out to be much more economical. For charging the batteries of the storage battery vehicles it is customary to employ motor-generator sets and to locate these at a point easily accessible to the vehicles. This is usually at a point on the docks. In such cases a-c. energy would be fed to the motors of the battery charging motor-generator sets from the main substations. For meeting the requirements of the alternating current load of the larger a-c. motors, including those driving the d-c. generators of the motor-generator sets, there is usually installed transformers stepping down the potential of the power from that at which it is received to that satisfactory for distribution and motor operation, namely, 2300 volts, unless the power requirements of the docks are not sufficient to warrant such a high potential, in which case 460 or 230 volts is invariably employed. The bus from which this power is distributed is usually known as the main low tension distribution bus. In those cases warranting the employment of 2300 volts for the main distribution system it is always necessary to distribute a-c. energy at a lower potential (460 or 230 volts) for operating the motors used for driving the various small conveyors and portable machines. Energy in this form is readily made available through the installation of transformers operating from either the high tension or main distribution bus in the main substation.

It will be seen that the character of the substation for any particular dock is entirely dependent upon the particular conditions obtaining at that dock and its form will be largely determined by the potential at which power is received, the magnitude of the load, the distances between the substation and load centers, the sizes of the installed motors, and the ratio of d-c. and a-c. power requirements.

Apparatus for Alternating-current-Direct-current Conversion

In the selection of apparatus for the production of d-c. from a-c., the choice lies between synchronous converters with their corresponding transformers, induction motor-driven motor-generator sets, and synchronous motor-driven motor-generator sets. Where the size of the set is sufficient to permit of the economic use of a synchronous motor as a result of its high power-factor, the choice usually narrows down between the converter and the synchronous motor-generator set. Each has its points of advantage. The converter with transformers is, as a rule, less expensive and has a higher overall efficiency than the motor-generator set. On the other hand, there is practically no control of the d-c. potential, which is a function of the a-c. voltage supplied to the converter; the d-c. system is tied in electrically with the a-c. system and disturbances on the one are reflected in the other; and the converter is primarily a unity power-factor machine (with special design features it might be arranged to operate at slight variations from unity power factor). Although the synchronous motor-generator set might have a slightly lower efficiency and be a little more expensive than the converter and transformers of like capacity, there is no electrical connection between the a-c. and d-c. ends, and therefore the operator has complete control over the d-c. potential irrespective of variations in a-c. voltage; also the motor may be designed for any amount of leading power-factor (usually 85 per cent), which is particularly advantageous in correcting the power-factor of the a-c. system, as it is becoming common practice for power contracts to specify a minimum lagging power-factor with a penalty in case the power-factor of the load falls below this minimum. As the class of service to which a-c. motors are subjected in dock work is conducive to low power-factor (motors operating under-loaded) the production of as much leading reactive kv-a. in installed synchronous motors as is possible is desirable, and often this amount is insufficient to meet the requirements of certain central station power contracts, thereby necessitating the installation of synchronous or static condensers for no other purpose than to reduce the lagging reactive kv-a. of the power purchased.

The momentary overload capacity of the two types of machines is about the same in machines of like capacity and equally modern design.

Distribution Circuits

In laying out the distribution system, particularly in the case of those docks devoted to the handling of miscellaneous package freight, careful attention must be given to the distribution systems. After deciding upon the load centers and corresponding loads and the location of the generating station or substation, we must calculate the sizes of conductors and number of circuits, and determine the routing to the load centers. These routes must be calculated both for potential drop on the basis of the maximum possible momentary demand and for safety against abnormal heating as a result of the normal effective load.

As a rule the feeder circuits for docks devoted to the handling of bulk freight feed fixed loads; i.e., most of the loads are in the form of motors permanently located or arranged for motion within a predetermined and limited area. The maximum load that these motors will be called upon to carry

U. S. Docks in France for Handling Army Supplies can also be calculated fairly closely. Hence the feeder requirements for this class of service can be very closely approximated and installed without much fear of ever being materially overloaded.

In the case of docks designed for handling miscellaneous package freight, where a large part of the load is in the form of motors operating portable freight handling apparatus, the selection and location of the distribution circuits feeding this class of load present added complications. Such feeders instead of supplying energy to a definite number of known loads must feed a series of outlets located at convenient points from which the different classes of portable freight handling apparatus may receive power at will. A sufficient number of these outlets of proper capacity must be located throughout the docks and warehouses at such places and in sufficient numbers to permit of the operation of the maximum number of pieces of apparatus that any possible condition will warrant. The circuit feeding any number of these outlets must be of ample capacity to carry this possible load, for experience shows that when the work of the designing engineer and builder has been completed and the installation turned over to the operating force, whose duty it is to handle tonnage, limitations and assumptions are usually forgotten.

The circuits in this class of work must receive more than ordinary mechanical protection. It is customary, as far as possible, to so place all circuits that chance of mechanical injury from moving apparatus or freight is reduced to a minimum. It is considered, perhaps, the best practice to place all conductors in metal conduit, preferably imbedded in the main structure; or, where this is impractical, the conduit should be securely fastened to the structure to prevent possible injury. Where the duct system is imbedded in concrete it is possible to employ fiber or tile ducts for the larger sizes, thereby effecting a considerable saving in cost and at the same time maintaining a high standard of construction. Besides the mechanical protection afforded by placing all circuits in ducts or conduits, there is obtained the added safety to the labor working in the vicinity of the circuits, and protection against fire resulting from an exposed arc caused by a short circuit.

Of course, in the case of the alternating current circuits, all lead sheathed circuits should be in the form of multi-conductor cable; and all circuits placed in conduits should have all phases of the same circuit in the same conduit. This is to eliminate the currents that would be induced in the sheath or conduit and might cause undue electrical losses and serious heating.

Cable circuits exposed to water or a moist salt atmosphere, as for example those located in pier decks, should be protected against the effects of these elements by a lead sheath. Feeders located in dry places and exposed are usually furnished with a flameproof compound covering; and those in conduits with simply a double braid covering having a weatherproof finish.

For the smaller sizes of low voltage conductors rubber insulation seems preferable; while for the larger cables, either varnished cambric or paper insulation with lead covering is commonly used.

It is customary and highly advisable to run all lighting and power circuits separately to prevent variations in lamp brilliancy as a result of voltage fluctuations caused by load changes on the power system, to guard against the possibility of having the lighting system out of service as a result of a short circuit on a power circuit, and to permit of the control of illumination throughout the property without affecting the supply of energy to the power consuming apparatus.

Protection Against Overloads and Short Circuits

As the operation of the power driven freight handling equipment is usually entrusted to persons with but little or no knowledge of electrical apparatus, it is particularly necessary to protect all apparatus entrusted to their care against harm resulting from overload. The protection at the motors usually consists of fuses for small motor, and suitable overload and under-voltage relays for the larger motors arranged to open the circuit of the protected motor through the controlling circuit breaker or compensator switch.

The feeders leaving the main substation are usually fully protected automatically, but arranged to open under short circuits rather than overloads, reliance being placed on the protective equipment located at the motor to open its corresponding circuit in the case of an overload. When relays are used for the automatic control of these circuits it is possible to so select them that in case of a failure on any one feeder that feeder will be automatically tripped by its corresponding control relay, thereby permitting service to be maintained over all other circuits without interruption.

The Warehouse Its Place in the Modern Community

By B. F. Cresson, Jr.

Consulting Engineer, Harbor Works, Piers, Docks, Warehouses, etc., New York City

A better understanding and appreciation of the value of the warehouse in community development and service will be obtained through reading this article, for the author is well qualified to discuss the subject. In addition to explaining the function of the warehouse and its relation to the population it serves, he treats of such necessary considerations as location, architecture, and machinery equipment. Particular attention is called to his remarks concerning the need of better co-ordination of shipping and storage facilities.—Editor.

B. F. Cresson

THE warehouse is in many respects as essential to the great city as is the railroad. It constitutes the flywheel that stores up and then releases energy vital to the machinery that makes possible the concentration of great populations.

The day to day supply of food products cannot be made to match the demands of great cities without the warehouse to make available the seasonal variations in production and to correct the delays and irregularities in transportation.

Cities cannot be self-contained in the production of supplies for the maintenance of their existence, and commodities must be borne from all parts of the world to meet the daily demands.

When our cities were small it was possible to supply their daily demands for food from nearby farming districts, the transportation being effected by the market wagon, and it is only by the development of the railroads and the warehouses with the accompanying facilities for preservation of food products through refrigeration that it has been possible for our great cities to come into existence.

The warehouse is essential not only for the maintenance of a continuous supply of food, but it is necessary also in the collection and distribution of raw materials for manufacture in our great centers and for the temporary disposition of manufactured products created within our industrial districts awaiting the demands of shipments.

The warehouse is likewise an essential part of our transportation systems and is needed in order that our railroad cars may be released from service as storage and utilized more and more for transporting commodities, and that our ships may have convenient space where incoming cargoes may quickly be placed and outgoing cargoes assembled in order that the shortest possible time may be spent by the ships at the docks, where the ship is earning nothing.

It is fair to say that generally speaking there is a lack in this country at least of co-ordination between the warehouses and the ships, and in the most modern planning of shipping and rail terminals this condition is being realized and the value of the warehouse as an adjunct to rail and shipping facilities is being more and more recognized.

The failure to construct the warehouse as part of the terminal facilities has probably been due to the hesitation on the part of the railroads and of the public authorities—and these are the interests that have mostly constructed our terminal facilities—to embark on a business which is not directly concerned in transportation. The railroads have provided means of receiving and despatching goods along their lines, and public authorities have constructed docks and piers where ships may be loaded and unloaded; but there has not been the disposition on the part of either to provide facilities for conducting warehousing. This has been developed largely as a separate line of business, not properly coming within the scope of the railroad or of public docking facilities. Many of our delays to railroad cars and to ships at terminal points may be said to be due to the lack of supporting warehouses as a part of railroad or shipping terminals.

Certain private terminal operators have appreciated the necessity for storage in addition to rail and shipping facilities and in the construction of their terminals have taken the broader view; the result has been that economies have been effected in transportation through private terminals, which has generally not been possible through either the terminals constructed by the railroads or the terminals constructed by the municipalities.

New York has at least two examples of the co-ordination of shipping and storage facilities in the plants of the Bush Terminal Company and of the New York Dock Company, and there are other private terminal companies at various ports on the Atlantic and Pacific, which have appreciated the situation and have built plants in which the warehouse has been an integral part. The authorities in some of our Pacific ports, appreciating the value of supporting storage at the water front, contemplate in their plans the provision of storage in order to relieve the transit sheds at the shipside from the necessity of acting as warehouses, and this is unquestionably the correct principle in modern port design.

When this country entered into the great war it realized the necessity of providing the most rapid means of getting supplies aboard ships for the Expeditionary Force abroad, and in the Army supply bases constructed at Boston, New York, Philadelphia, Norfolk, Charleston and New Orleans, adequate warehousing and storage space was built as part of the shipping facilities. While the full use of these army bases may not now be justified in commercial practice, the time will come when these bases, constructed principally to expedite the shipment of supplies for the army, will be efficiently and actively used, and the value of the storage in connection with the wharfage will be appreciated.

Taking the matter of warehousing in its broader aspect, not necessarily as a part of the transportation systems of our great cities, the great demand for space has created high rates and has led private warehousemen to construct new buildings or make over old ones, not so much with a view to convenience to transportation facilities as to convenience to particular business centers, relying largely upon the truck, either horse or motor, for transportation to and from the warehouse. Space was needed, and with the demand that existed and now exists, the warehouseman could rent his space on favorable terms, not being greatly concerned with the expense of bringing commodities to or taking them away from the warehouse. In the long run the public pays that additional cost of transportation and the warehouse that is most conveniently located with respect to transportation facilities will be the warehouse that will be of the greatest value to the community.

Owing largely to the great demand for warehouses, they have been scattered throughout our communities and it is interesting to note that in the port of New York, which embraces the entire Metropolitan District of New York City as well as many of the New Jersey communities, where 85 per cent of the railroad business, exclusive of coal, reaches and leaves the port on the New Jersey side, about 80 per cent of the warehouses are on the New York side of the port, dependent for their connection to the New Jersey railroads on a floatage service as well as drayage.

It is not intended to convey the idea that all warehouses must be at the water front or adjoining the terminal yards of the railroads. Certain warehouses for domestic furniture, for certain high-class manufactured products, and the raw material needed for them, are better located near the center of the population and industry; but the point that the writer wishes to make is that warehousing should be provided at the terminals of the railroads and ships as a necessary adjunct to railroad and shipping business.

The design of the warehouse should be a matter of great concern; the owner should not be content with merely so many square feet available for storage, but he should be sure that he has the proper floor load capacity, the proper clear height between floor and ceiling, the proper elevators and other mechanical equipment for raising and lowering between floors, and the best and most convenient access to the doors of railroad cars, the tailboards of the trucks and the transit shed alongside the ship, as well as the most efficient fire protection.

The matter of machinery at the terminal warehouses is of great importance and special consideration should be given in the design to the location of elevators, their size, capacity and speed, in order that maximum economic loads may be handled within a minimum of time and that the movement between the elevator and the storage pile may be as short as possible. The warehouse should be designed and laid out with the operating plan clearly in view; the space that may be considered available for storage; the space that must be reserved for aisles and for the operation of the elevators; whether the location and size of the plant will warrant operation by tractors and trailers or by load-carrying trucks, or by other means as conveyors, moving platforms, telphers or any other mechanical device or combination of devices. In certain operations exterior hoists, commonly known as "whip hoists," may be found of great use, and where the character of the commodity and the length of storage warrants, tiering machinery would constitute a necessary part of the equipment. Modern machinery plays as important a part in the operation of a well-designed warehouse as in any other part of the terminal plant.

Proper warehousing facilities are of the utmost value to the railroads, to the ships, and to the people at large, and the appreciation of this fact will do much to advance the modern science of transportation.

Warehouses

By J. J. Matson

Power and Mining Engineering Department, General Electric Company

Although warehouses are of ancient origin their development has been sadly neglected when compared with that of the common carriers they serve. This condition has undoubtedly resulted from a failure of the general public to realize that the warehouse methods used are inefficient and responsible for unnecessarily high transportation charges. The subject is now however receiving intelligent attention, and constructive effort is producing the long needed results. Mr. Matson outlines below the fundamental principles that should be observed in the layout and construction of warehouses, and describes the various types of freight handling equipment that promote their efficient operation.—Editor.

J. J. Matson

From accepted practice, the word "terminal" when used in regard to traffic means the end of one common carrier. This is, in reality, a misnomer, for a terminal may also be a junction or place of changing from one common carrier to another or from a common carrier to trucking systems for ultimate distribution.

It can readily be understood that incoming and outgoing traffic at a terminal will vary considerably, and suitable provisions must be made for storing the excess tonnage received until suitable provisions can be made for reshipping or distribution. This, then, makes it desirable that every terminal, regardless of size, should have a suitable warehouse for taking care of this overflow.

Consider an example of what ensues at terminals where sufficient warehouse capacity is not available: A shipment arrives which involves the transference of the freight from railroad cars to boats; no warehouse space is available and the boats for receiving the freight are not docked. The railway cars themselves are then used for storage space and this not only ties up yard trackage but also removes from active circulation that number of railway cars. Not only is a loss sustained by the railway company due to idle equipment, but also by the shipper due to demurrage. Needless to say, both of these expenses are ultimately paid by the consumer as both enter into the cost of the material as paid by the retailer.

This was a very common occurrence during the early part of the war and continued until the large army bases and terminals were built. They lessened this congestion to a great extent but were inadequate to entirely do away with congestion.

It has been estimated by Mr. A. H. Smith, president of the New York Central Railroad, that the cost of distributing foodstuffs to the people of New York City alone is increased by $200,000 a day on account of inadequate warehouse capacity and railroad facilities. To a family of five, this means an additional expense of approximately 40 cents a day or $146 a year, assuming that the $200,000 wasted through inadequate equipment will be doubled by the middlemen's profits. Capitalizing the $200,000 a day at 6 per cent we find this waste to be the interest on $1,200,000,000. This is a large amount of money and it is very evident that from three to five hundred million dollars could be economically expended to increase warehouse capacity and railroad facilities for the entire city of New York. Needless to say, this amount of money would accomplish wonders. What has just been pointed out concerning New York is equally true of all other large cities and is also true in a smaller way of practically all terminal and warehousing undertakings.

Warehouses have been used since the dawn of civilization. In fact, it might be said that from the moment man stopped a day-to-day existence and began to prepare in advance for his daily needs, we have had warehouses. Many examples of warehouses are given in the Bible as noted from the frequent references made to the large granaries that Joseph used for the storing of his grain in the seven years of plenty for use in the seven years of famine. Also, we read about the large store houses of the Persian kings, of Assyria, Arabia, India and even China. These were principally used for the storing of silks, grains, wines, spices, etc., as they were the commodities most commonly dealt in during those periods. From this origin, the practice of storing in warehouses can easily be traced down through the middle ages and at present there are standing in Europe many artistic examples of warehouses which were built in the middle ages.

From these statements, it develops that the warehouse is a building or group of buildings used for the periodic receipt and gradual distribution of commodities to the ultimate consumer. A general classification of warehouses is:

Merchandise
Household goods and furniture
Implement storage and transfer
Cold storage
Port and railroad terminals
Special warehouses which are combinations of the above general types.

Each of these types has many details of construction to be investigated. Great care should, therefore, be exercised in laying out and erecting warehouses, always bearing in mind that unless efficiently designed, the warehouse will sooner or later be a liability rather than an asset. This is due to its certain future competition with warehousing enterprises which have been carefully designed after taking into account all existing conditions.

The length of time goods are in a warehouse will vary with the type of freight. For example, rapidly moving articles such as foods stay on the average of about 15 days, while ceramics, hardware, etc., are on the average in the warehouse approximately 60 days. These figures are based on warehouses situated at terminals. On merchandise and household goods it is very hard to obtain an average time in storage. This is due to the extremely varied field that these types of warehouses handle. As to the cold storage warehouses, it has been brought out in investigations made by Congressional Investigating Committees and from other information as given out from time to time, that materials are kept in cold storage for great lengths of time. There is a strong movement at present under way to reduce the allowable storage time of this type of material.

A ship's cargo is frequently made up of all the different types of freight, and it is gathered from all directions. It is therefore evident that a warehouse for handling freight which is ultimately to be loaded on boats, should be located near the boat slips in order to reduce handling costs, as practically 90 per cent of export trade lies over in warehouses at point of embarkation.

Many people who have made a study of freight handling conditions point out that it costs as much and sometimes more to handle a ton of freight through a terminal as to ship it between terminals. This handling includes the breaking up of a cargo, removing to the warehouse, reclaiming from the warehouse and again reloading on a common carrier or trucking system for further distribution. In case of short hauls, such as between Philadelphia and New York, the terminal charges will be from 10 to 15 times the haulage charges.

Bearing this fact in mind, together with the fact that the costs of all inefficiency at terminals must be borne by the ultimate consumer, it is obvious that considerable time, thought and energy should be devoted to the layout and operation of any warehousing undertaking.

The first thing to be considered is the selection of a proper site. A site should be selected that is easy of accessibility and is of such size and location that the buildings can readily be expanded. Bearing in mind the first two items, a thorough study should be made of the district to be served and methods determined on for obtaining the business from this district. The buildings themselves should then be designed for a gradual increase in business, but in order to keep the overhead expenses down, they should not be erected too far in advance of this increase in business.

In order to permit of easy and uniform expansion, it is suggested that the unit plan of building be adopted. The unit plan is to have similar buildings erected, each being of a convenient and compact size. An example of this type of building is the Bush terminal in Brooklyn. Here each warehouse consists of a building built in the form of a "U." Between the two wings there are railroad tracks sufficient to accommodate 26 railroad cars. Each car can be unloaded or loaded from a platform at either wing. When expansion is required, another building of this same layout and construction is erected.

A fine architectural building is not required nor is it suitable; substantial, businesslike buildings are much better and can be built at a much lower cost than can elaborately designed structures. This reduces first cost, which in turn reduces overhead charges and ultimately service charges.

In order to efficiently handle materials within the warehouse much thought should be given to the internal arrangement. This refers to the laying out of aisles, the proper location of elevators, the planning of lighting, and the desirability of installing mechanically operated handling apparatus.

The problem of lighting in the warehouse is one that must be given considerable thought in order to intelligently plan for the utilization of the various parts of the building. Well lighted aisles should be provided in order to prevent accidents which not only jeopardize the operator's safety but also the safety of the material being handled. Also, sufficient light should be provided for conveniently working the different piles. Thus the arrangement of windows will depend on location of aisles and storage space. Large windows at the ends of aisles are usually desirable.

In the design of a warehouse, special attention should also be given to the fire underwriters' rules which deal with warehouses, primarily keeping in mind the fact that the building materials used, the type of material being stored, the number of floors in the building, and the ratio of fire walls to floor space play an important part in determining the insurance rates. The fire insurance underwriters are glad to co-operate with the warehouse men in planning buildings to best meet the fire underwriters' code, and those who are interested in warehousing should avail themselves of this opportunity, thoroughly discussing with their insurance agents the best way to reduce insurance rates. In general, the installation of adequate sprinkling systems, and the use of as many fire walls as is practical, when considering space economy, will reduce insurance rates. Also it is advisable to isolate various classes of materials as much as possible. For example, inflammable materials should not be stored together with furniture or other similar material.

Another important feature is the height of ceilings. This will vary considerably with the types of material to be handled and the manner of handling. For example, if manual labor is to be used for the tiering, the ceilings should be lower than when mechanical methods are employed. This is on account of the decreased efficiency of a man as he tiers to any great height, it being recognized that when lifting packages of 100 lb. the limit is about 5 ft. and thus, to pile very high requires many men. With tiering machines, the height to which materials can be automatically piled is much greater. Of course, two men are usually required to handle goods at the top of the pile. But as the pile grows additional men are not required, as the machine is adjustable and can deliver goods at any desired height within reason. If materials are to be handled, which on account of bulk or weight should not be tiered, the ceilings should be low to prevent wasted space between material and the ceilings.

In designing a warehouse, provision should be made to provide storage space for materials that are to be in storage an unusually long time. Unless this is done, congestion and confusion will result due to the more rapidly moving material being blocked by that which is to be in storage for some time.

The discussion of suitable apparatus for handling freight at warehouses will be limited to the movement of material within the buildings.

It has always been recognized that to move material on wheels is much easier than to slide or carry it. For this reason hand trucks have been used for a long time in transporting materials and experience has shown that even with the advent of the tractor and trailer the hand truck is, in most cases, economical for very short hauls, up to 150 ft., and when handling packages of less than 250 lb.

The introduction of the tractor and trailers (which is being used in increasing number all the time) has reduced handling costs a great deal, as all material is kept on wheels as much as possible. It is important to so utilize a tractor as to prevent idle moments waiting for a load of trailers.

Power for tractors is furnished from a storage battery which usually has sufficient capacity to permit of 12 hours steady operation. The batteries are then recharged at the charging station, which is a part of the warehouse equipment, and in case severe duty is required it is common practice to give a short charge to the batteries during noon hour. Any of the recognized makes of batteries will be supplied by the tractor manufacturers.

Investigations have shown that much confusion is avoided and efficiency therefore increased by having certain definite routes of travel for tractor and trailer trains. This has been minutely worked out in such undertakings as the Brooklyn and Boston army bases, where one-way traffic is enforced for all tractor and trailer trains. In order to accomplish this, each trailer when loaded is manually moved the few feet necessary to bring it adjacent to the line of travel of the tractor. Each tractor is equipped with a crew of two men, one acting as operator for driving and the other corresponding to the brakeman on a railroad, it being his duty to hook on and drop off individual trailers at the desired locations. It has been found practical to hook on trailers having a capacity of approximately 2000 lb. to trains moving at the rate of 3 or 4 miles per hour. It is also possible to disconnect the trailers under similar conditions. With this method of operation, one tractor replaces many men with hand trucks. This is due to the greatly increased tonnage per hour per man when using tractors and trailers as compared with hand trucking. Trains of 7 to 8 trailers are usually found most economical, but there are installations where 20 to 30 trailers are handled by one tractor and done so economically. This, however, is the exception.

In reaching a decision as to the number of tractors necessary, we should bear in mind the relative merits of installing tractors on each floor and the practice of running the tractors onto the elevator and moving them to the required floor for the distribution of trains. It is evident that many questions, such as those of first cost and percentage of time the tractors are operating, will in a large degree enter into this decision. The installation of tractors on each floor permits more efficient use of the elevators.

The trailers hauled by the tractor are four-wheel trucks usually having a capacity of about 2000 lb. and average platform of about 3 ft. wide by 6 ft. long. Practice shows that it saves confusion and increases efficiency to have only one consignment per trailer. In case of larger consignments more than one trailer may be used but for the sake of efficiency never should one trailer be used for two or more consignments. Many warehouse companies find it advantageous to carry a large reserve of trailers so that the material can as far as possible be kept on wheels from time of receipt until time of dispatch. This, of course, primarily refers to materials that are not to remain in storage for a long period of time.

Another type of apparatus that is widely used in warehouses is the industrial truck. It has a capacity of from 2 to 4 tons and, as in the case of the tractor, derives its power from storage batteries. It is sometimes equipped with a small hand operated crane for lifting heavy loads thereby increasing its scope of application.

There are two distinct types of industrial trucks, one having a stationary platform and the other an elevating platform. Trucks of this first type are loaded either manually or by cranes; those of the platform type are rolled under a skidboard on which the load is piled, raised, and carried to the desired place. The load is deposited by lowering the platform. The platform is usually raised and lowered by a foot treadle. Some hand trucks are built on the same principle.

In all warehouses some heavy loads will have to be lifted, the actual size and frequency of which will vary greatly. In order to facilitate this lifting, it is necessary to have some type of crane. Three types are in general use, viz., the storage battery crane

Fig. 1. An Interior View of Building "B," Army Supply Base Brooklyn, N. Y.

which is portable and can be taken to any part of the building; the overhead traveling crane, and the jib crane which is mounted on the wall or on pillars throughout the warehouse. The storage battery crane has the advantage of portability but has the disadvantages of taking up floor space and of not handling as heavy loads as do overhead traveling cranes. The overhead traveling crane has the advantage of being off the floor but also has two disadvantages; first, provision must be made at the time of erecting the building for a suitable structure to withstand the heavy strains ensuing from the large crane; second, the overhead traveling crane is limited in service to the area included within its runways. The third type is stationary and thus serves a much less floor area than either of the other types.

The Brooklyn army base has installed several overhead traveling cranes for handling heavy articles of war destined to go through this terminal.

Fig. 1 shows the interior of one wing of the warehouse at the Brooklyn army base. Skylights are used to permit the use of enclosed railroad tracks together with natural daylight. The 5-ton overhead traveling crane shown in the upper foreground handles

Fig. 2. Shells as Piled at the Beginning of the War. Piles were low and uneven

materials between the platforms on either side of the tracks and the cantilever reenforced concrete receiving bins, which open into passage-ways through the upper storage floors. These bins are staggered to permit free handling to all floors.

Experience has taught that considerable time and expense may be saved in handling a uniform cargo to and from steamers, if it is systematically piled on and securely fastened to cinchboards, the whole being kept intact through its transportation. This makes a convenient package for handling not only to and from the ship but also in the warehouse.

There are two types of tiering machines in general use about warehouses. One of these is the portable inclined elevator which consists of a movable belt or wood slab platform equipped with suitable flights or anchorages for preventing the material slipping back. Packages are delivered to men at the top of the pile and the final stacking is done manually. The height of tiering is adjustable over considerable range. The second is of the vertical type and has a maximum lift of about 12 ft. This type may be mounted on a revolving platform and is either manually or electrically operated.

Gravity conveyors either of the portable or stationary type are also useful in handling uniform materials. The portable type is most extensively used. A portable power-driven conveyor is adapted for handling uniform material such as bags of coffee, beans, sugar, etc., and boxed goods. It has a capacity of about one ton per minute and is usually made up in small lengths, each having its own source of power, thus making possible the extension of the system. It is very difficult to use a conveyor such as that just described in conjunction with an inclined elevator for the handling of miscellaneous cargoes because of the wide variation in weights and dimensions of packages handled. Both steel and wood rollers are used with gravity conveyors, each having their place. The wood rollers are best where dry materials are being used, but if subjected to damp conditions they will warp and swell. The steel rollers are easier replaced but in case of damage they cannot be repaired. Steel rollers usually become bent when damaged while wood rollers either chip or wear oval due to the grain of the wood. When they become oval they are useless, but chipping does not prevent further use.

Overhead monorail or telpherage systems are capable of installation in most warehouses and in most cases show a very economical operation. They have a capacity up to about 10 tons and a maximum speed of about 50 ft. per minute. The simplest installation consists of one single monorail, but this has the disadvantage of serving only the territory directly under it. There has been

Fig. 3. Shells as Piled at the Closing of the War, Showing Decreased Floor Space Required Due to an Extensive Use of Dunnage

developed, however, an adjustable loop for use with a monorail system. This consists of two traveling bridges, each equipped with monorail track which feathers into the main line track. The bridges are at right angles to the main track and can be spaced practically any distance apart up to the length of the building. This greatly increases the flexibility and area served.

The best examples of warehouses properly laid out for utilizing mechanical handling apparatus are the Boston and Brooklyn army bases. Both were designed and put into operation by exceptionally capable men who spent much time and study in the proper co-ordination of elevators, tractor and trailers, conveyors, tiering machines, etc., which are extensively used in both enterprises.

The changeover at army bases from war to peace conditions has been partially completed, and it is noticeable that some of the mechanical handling apparatus is not being utilized under peace conditions. This is due first, to the fact that the amount of material now passing through warehouses is much smaller, and second, to the fact that peace conditions have changed, to some extent, the character of goods being handled at warehouses. The army warehouse at Schenectady is a good example of this condition, for at present there is much material handling apparatus that is not being used or is only partially used, due to decrease in amount of material passing through.

This emphasizes the need of a careful canvass of the field before selecting mechanical handling apparatus, thus insuring the greatest efficiency and economy. The government could not, however, look into the future in this way, its one aim being to speed up material handling as much as possible. This has resulted in excess apparatus on return to a peace basis.

One of the most important points to consider in a warehouse is the elevator installation. Many questions enter into the design, such as speed, capacity and location. It is more economical to install elevators in groups or banks at certain definite intervals than to uniformly distribute them throughout the building. Grouping reduces the time wasted by a man going to one elevator, finding it in operation, and having to go to another. If the elevators are installed in a bank it is practically certain that one will be unoccupied and at his service.

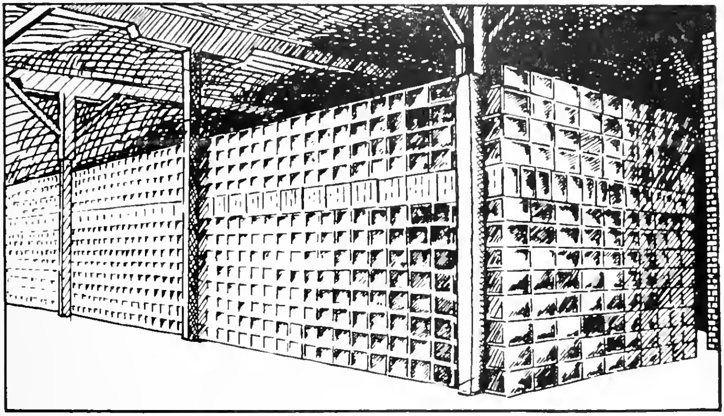


Fig. 4. A Row of Cases Inverted Serves as Dunnage in Piling Cases of Canned Tomatoes

The elevator speed should not be so fast as to require jogging for accurate floor landings, as the time thus consumed off-sets to a great degree the time gained by the higher car speed. A speed of 150 ft. per minute is about the limit for single speed elevators. The accuracy of landing varies as the square of the elevator speed.

With direct-current elevators, slow down is easily obtained. The "micro-drive" feature, when applied to alternating-current motors, gives very accurate floor landings. Accurate landings can also be made by using two-speed alternating-current motors. These have the great advantage of being much cheaper and simpler.

The elevator installations at both Brooklyn and Boston army bases are automatic, their movements being controlled by one central operator who is situated at a switchboard from which he can control the movements of any car in his bank of elevators from one floor to any other. In case an elevator is desired, this operator is notified by telephone and he dispatches a car there for service. The "trailing light system" is used to keep an accurate record of the position of the cars at all times.

The dictionary defines the word "dunnage" as pieces of wood, mats, boughs or loose material of any kind laid on the bottom of the hold for the cargo to rest upon to prevent injury by water or chafing of the cargo due to shifting. Dunnage to the warehouseman has an entirely different meaning. To him it means the use of wood or other materials to permit higher tiering, thus economizing in floor space. Dunnage most often takes the form of timbers of even cross-section cut into even lengths. Most of this is reclaimed from crating and similar sources which are common about warehouses.

Figs. 2 and 3 show the greatly increased efficiency obtained in the piling of small ammunition when dunnage was used. Also, it will be noted in Fig. 3 that the pile is much neater than when piled as in Fig. 2. The shells in Fig. 2 were manually piled, while machines were used in tiering those in Fig. 3. Machine piling also effects a great saving in expense.

Another place where dunnage is essential is in the piling of mattresses and similar materials which will not keep their shape. By the use of small pieces of wood they can, however, be piled.

When piling boxes very efficient dunnage can be obtained by inverting a row of boxes. As the boxes are not cubic they will cause a break in the tiers and lend stability to the piles. Fig. 4 shows very clearly the use of such dunnage.

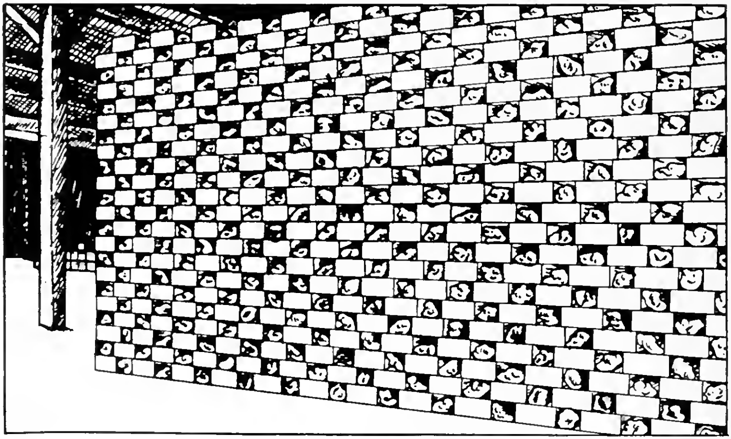


Fig. 5. Axes and Axe Handles Piled so as to Permit Easy Reclaiming. The heads are packed in boxes of one dozen each and the handles are wrapped in the burlap bags shown between the boxes

Fig. 5 illustrates the method used by the U.S. government to pile its boxes of axes and axe handles, permitting rapid reclaiming. Each box contains 12 axes and each burlap bag contains 12 handles. The handles are in vacant spaces between the boxes, thus keeping both close together. This is a rather unique method of using the material itself as dunnage.

In closing, it might be stated that it has been the writer's aim to point out some of the most fundamental, underlying principles pertaining to the proper design, construction and economical functioning of warehouses. No attempt has been made to conclusively cover any of the various far-reaching phases in this article.

The Field for Electrically Operated Material Handling Machinery

By F. T. Smith

Power and Mining Department, General Electric Company

The application of material handling machinery is bound to have an immense future because of the vast scope of the field involved, the huge quantity of goods handled, and the economic pressure which will be brought to bear upon the managements that employ antiquated methods of handling material by manual labor. The following article discusses the general situation, describes several well-designed installations, and makes reference to the various units of equipment now available.—Editor.

F. T. Smith

The problem of commerce has been characterized by the late James J. Hill as: "To get it from where it is to where it ought to be." This would apply equally well to the handling of material at terminals. How to move heavy loads and light loads, small packages and large unwieldy packages, over both short and long distances in the least time and in the most economical manner, constitutes the problem of modern freight handling.

A recent survey of the field for mechanical handling equipment showed that there is a demand for over 200,000 units in the industrial section alone; such equipment as industrial trucks, tractors, lift trucks, industrial locomotives, portable cranes, portable conveyors, and portable electric hoists being included. The investigation also demonstrated that only five per cent of the plants in the country are extensively employing machines of the types mentioned. It further disclosed that but 35 per cent of the manufacturers are familiar with mechanical handling equipment and its function, and that among the remainder a very great many are entirely unacquainted with the details of even the minor types of such machines. In the iron, steel, and metal working industry, 30 per cent of the managers could not mention a single manufacturer of plant transportation equipment, such as trucks, tractors, conveyors, etc. The investigation further disclosed that the potential requirements of the railroads are enormous.

The railroads are well termed, "The Arteries of the Country." They form a huge network with over 100,000 terminals and transfer points in the United States. To reduce to a minimum the time required to load, transfer and unload 2,400,000 freight cars on 231,000 miles of track is the job of the railroads in America today. It is estimated that 150,000,000 tons of freight are handled in the port of New York annually. An authority has stated that by the installation of up-to-date equipment for material handling, the estimated average saving in cost is 40 per cent over old methods. Roughly speaking, one million men are engaged in freight handling in the United States and they receive more than one billion dollars annually. Thus, a 40 per cent reduction in the cost of handling would result in an enormous saving.

Inland Waterways

The question of water transportation has recently been given considerable thought. On the Mississippi River there has been instituted a water freight line from St. Louis to New Orleans, comprising several fleets each consisting of one towboat and five barges, each barge having a capacity of 2000 tons or a total of 10,000 tons for a fleet of five barges. These floating freight trains maintain a $4\frac{1}{2}$-day schedule between St. Louis and New Orleans. Between Minneapolis and St. Louis there is also a water freight line consisting of 24 freighters and four tugs; these freighters or barges are 300 ft. long and have a capacity of 2500 tons each.

We are familiar with the New York State barge or ship canal, with a 12-ft. channel, connecting the Great Lakes with the Hudson river and the seaboard. There is also in operation the Cape Cod canal, connecting Boston Bay with Buzzard's Bay, which reduces materially the voyage from New York to Boston. With the contemplated deeper and wider canal from the Delaware river across New Jersey to New York Bay, and from the Delaware river to Chesapeake Bay, there will be an inland water route from Norfolk to New York, and thus through to the Great Lakes.

The construction of these canals means that men of affairs see the possibilities of inland waterway transportation and the big part it will play in future development. The War Department expects to put into service on the New York State barge canal a total of

Fig. 1. Heavy Duty Storage Battery Tractor Hauling Trailers Loaded with Coffee in Drafts from Pier to Storage

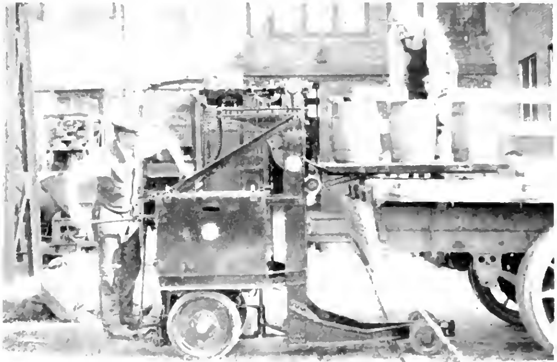


Fig. 2. A Tiering Lifting Truck Loading Barrels Onto an Auto Truck. The load is carried to the unloading point and raised to the desired height

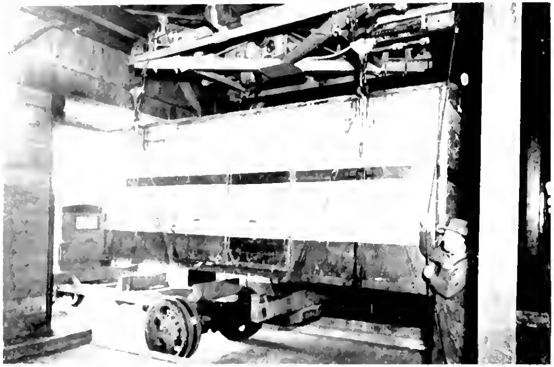


Fig. 3. Removing a Detachable Auto-Truck Body from a Truck Chassis at the Cincinnati "Motorized" Terminal. A general view is shown in Fig. 4

Fig. 4. View of Freight House Platform Showing Demountable Bodies Being Loaded with Freight That is Trucked Direct from Cars; Also Body Suspended Awaiting Its Loading on the Motor Truck Chassis

165 barges and towboats aggregating a cargo capacity of 141,450 tons.

Marine Terminals

The water terminal question is also a big one and is being met not only by the government but by municipalities interested in the success of waterways. The equipment of the many necessary terminals will require additional apparatus for the quick loading and unloading, economical storage, and efficient transfer of freight.

Over both rail and inland water transportation systems, freight moves in a never ceasing flow toward the terminals. To this point also come ocean-going ships to be loaded and unloaded. This continuous flow of freight over land and water makes the terminal the small neck of the "hour glass," with the choking point still further extended to the hatch of the ship and to the car door.

If we are to give our ships a quick turn around in port, if we are to release thousands of freight cars, if many thousands of tons of freight are to be transported and handled, if we are to hold the world trade, then we must keep our terminals clear. How will this be done? Shorter hours are in many places imperative, and heavy manual work must be lightened. In too many places is the man with the hand truck a conspicuous figure.

The piers must be built wider, they must be built to accommodate new and larger ships and to expedite the movement of freight. This means that there must be provision made for freight handling equipment, for storage space, for aisles, and for railroad tracks. Increased production, efficiency, and economy are some of the results assured by using mechanical equipment.

To relieve existing conditions and plan for a big future, let us consider some of the larger developments, accomplished or contemplated. Electricity has taken the lead, and among the greatest improvements has been the replacement of the hand trucker by the application of this greater power. The city of Seattle has spent millions of dollars for piers, warehouses, and modern equipment, thus making the port one of the foremost on the Pacific Coast. Plans are now under way for extensive improvements in the port of New York; and Philadelphia, Boston, Baltimore, and Portland, Me., are also looking well into the future possibilities of a port having modern handling facilities.

Trucks

Much attention is being given to the application of both electric and gasoline trucks of 1½ to 5 tons capacity for freight haulage and direct shipment. One of the slogans among many shippers today is "Ship by Truck." The use of highways, in addition to relieving railways of a portion of their freight, will save tremendous terminal expense and congestion as well as the cost of transferring to and from terminals. Motor trucks carry merchandise direct from shipper to consignee for there are no sidings, delays, or blocks along dependable truck routes. They operate on established routes, both express and freight, in every part of the country and form the backbone of the large motor transport fleet.

Fig. 5. A Portable Elevator, Electrically Driven, Piling Heavy and Unwieldy Bales of Sisal

Recent reports regarding the development of motor transportation indicate that there are more than 400 motor express lines in New York State. For the whole country, it is estimated that there are not less than 5000 such lines in operation.

A gasoline truck with an average speed of 15 miles an hour is best adapted to long hauls, 10 to 20 miles or even much longer. This type has unlimited mileage and has the advantage over the storage battery truck of being able to climb grades with very little reduction in speed. It costs more to operate than the electric, but with the increased speed it can carry more load in a given time.

A storage battery truck, having an average speed of 7 miles an hour and a mileage limitation of 45 maximum, 35 miles practical.

is best adapted to short hauls or what might be termed inter-city service. In other words, it is best adapted to a service where most of the time is spent standing or delivering over short distances; unloading a few packages, moving to another place, and unloading a few more. One disadvantage is that the operator must always work within the mileage capacity of the batteries. In other words, after making a number of runs during a busy day, he might not be able toward the close of the day to make a run which would carry him some distance from the charging plant without fear of being unable to return.

The first costs of the two types of trucks are comparable. The electric, however, requires additional apparatus in the form of battery charging equipment. Both types are valuable in their field of operation, in that they are free from track limitations.

In passing, we should not fail to mention contemplated airplane freight routes for quick dispatch of freight of limited quantity and size. Several routes have already been established. It is only a matter of time before special types of airplanes will be developed to carry certain kinds of package freight.

Terminals and Material Handling Equipment

The "motorized" terminal at Cincinnati is a big step in the right direction. Before adopting this improved method the terminal was one of the most congested in the country; now it is one of the most expeditious. Its equipment includes approximately 90 cranes, 360 electric hoists, overhead rails, motor trucks, and a plurality of interchangeable motor-truck bodies. These bodies are demountable and provided with hooks so that they can be lifted from the truck chassis by the overhead cranes. The lift and travel of each crane is controlled by an operator standing on the floor near the truck. The truck body is deposited on the floor of the terminal in line with other bodies that have been similarly unloaded, all of which have been placed conveniently near the waiting railroad box car. Through large doors at each end of the truck body, the commodity can easily be handtrucked a short distance to the railroad car. The reverse of this complete operation is carried out with equal facility. This procedure results in quick loading and dispatch across town, from one railroad terminal to another, and minimizes the long delay ordinarily experienced. The average cost of this work is 80 cents a ton as compared to \$1.20 charged by the transfer company with larries or \$1.12 to \$1.60 which it costs the railroads to haul their own trap cars. The freight car was not intended for a permanent storage and this is one method of releasing an average of 23 trap cars a day. This motor-truck service releases approximately 66,000 box cars a year from Cincinnati terminal usage for line movements.

The transfer company used 115 larries and hauled 38 per cent of the less-than-carload freight. To handle all the freight would have taken 250 horse drawn trucks. The motor company will soon be moving 1000 tons daily with 225 bodies and 15 to 16 chassis.

Another application that has proved successful is the installation of the tractor trailer system and the many types of industrial trucks at railroad terminals, marine terminals, and industrial plants. These efficient machines are demonstrating their ability in every part of the country.

The cost of operating the tractor includes:

Fixed charges, such as insurance, interest, taxes, and depreciation.

Operating charges, such as energy, tires, oil, grease, electrolyte, and water.

The approximate cost per hour is \$1.10 or 3 to 5 cents per ton on a basis of handling 330 tons of material per day for transfer at terminal points (not including loading and unloading).

The industrial load carrying truck:

(1) Moves a load equivalent to that of from 8 to 12 men with hand trucks.
(2) Travels from 5 to 7 times faster than a man.
(3) Saves the equivalent wages of from 6 to 15 men.
(4) Will pay for itself in from 3 to 9 months, depending on its use, care, and operation.

The average tractor train consists of eight trailers with an average total load of four tons. The number of trailers per train may be increased somewhat for a straight run or a train consisting of light trailers only. Each train is operated by a motorman and a man who hooks and unhooks the trailers. The trailers are loaded in the railroad car by two men and then pushed from the car to the platform. Each section of the platform or island platform is connected with the central dispatcher's office by telephone. If a loaded train is ready or there is a congestion of empty trailers, the dispatcher in that particular section telephones a central dispatcher for a tractor. The tractor is immediately sent to that section to haul the loaded trailers or empty trailers to that part of the platform designated by the central dispatcher.

The U. S. Army Supply Base at Boston is equipped with one of the most complete and modern mechanical cargo handling systems in the country, the mechanical appliances of which are electrically operated. This terminal consists of a loading and unloading pier and a large warehouse for storage.

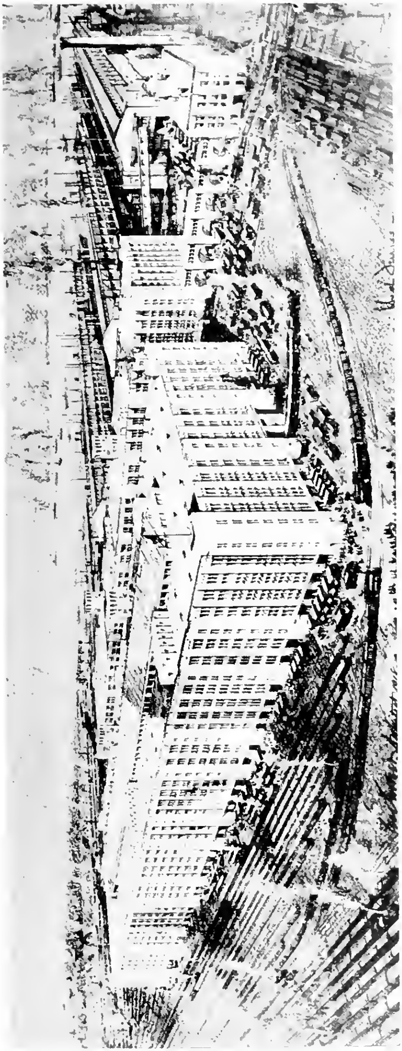


Fig. 6. Bird's-eye View of the Brooklyn Army Base, the Largest Shipping Terminal in the World

It is estimated that in ten hours 200 carloads or 6,000 tons of material can be unloaded from the cars and placed in the warehouse; 4,000 tons can be unloaded and placed in the pier shed; 100 carloads or 3,000 tons can be unloaded and stored on the first floor of the wharf shed; and that in about 55 hours four wharf-shed cranes will load an 8,000-ton vessel.

A terminal of this kind for handling package freight would approximate as nearly as possible a system so efficiently used on the Great Lakes for handling bulk material, would use all improved types of machinery for mechanical handling, and would include the installation of such apparatus as sub-station equipment, transformers, many types and sizes of motors, control, battery charging sets, wiring, lighting, etc.

A similar terminal, even larger than the one at Boston and equally well equipped mechanically, is located at Brooklyn. Others that might be mentioned are at Norfolk and New Orleans.

For conveyor and piling machines, a saving in time of one-third to one-half can be expected, with a cost per ton, for handling, depending on the rate prevailing for power and cost of labor.

Following are some of the appliances that help to speed up handling, reduce ship's turn around, and relieve congested terminals:

For Direct Unloading from Ship or Car to Shed or Warehouse:

- The crane, the mono-rail, and the fixed or portable winch.
- Many types of conveyors, industrial trucks, or tractor and trailers.

For Horizontal Movements:

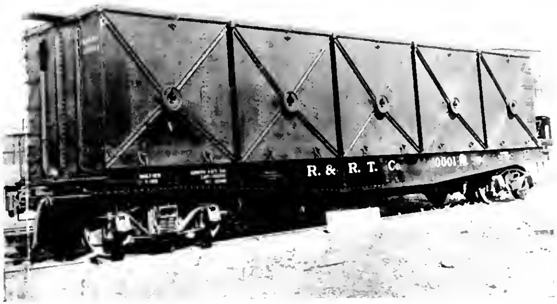
- The storage battery tractor with its fleet of trailers.
- The many types of the load carrying truck.
- The conveyor with power sections capable of being shortened or lengthened.
- The bridge-type crane.
- The mono-rail or telpher.

For Inclined or Vertical Piling:

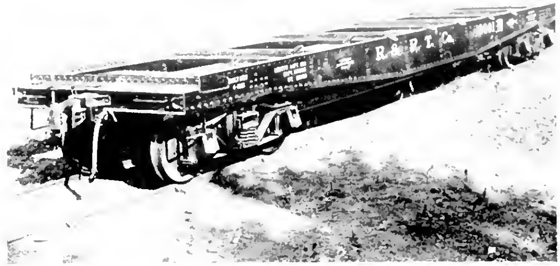
- The inclined conveyor for a commodity of one kind, packages, boxes or bags, uniform in size.
- The portable elevator or mechanical piler.
- The tier lift truck.

For Vertical Lift:

- The elevator with a platform of proper size to conveniently and economically carry loaded trailers and industrial load carrying trucks.
- The proper type of crane.
- The various types of portable and fixed winches and hoists.

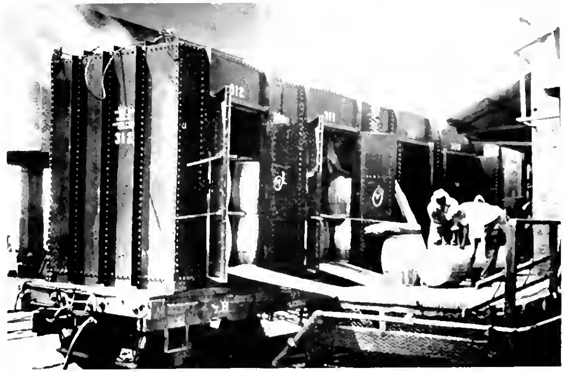


Five Unit Containers Securely Fastened and Mounted on an Underframe and Ready to be Transferred to Another Location



The Underframe Showing Construction and Clamps for Supporting and Holding Containers Securely in Place

Method of Removing One of the Containers from a Special or Standard Underframe or Flat Car



Four of the Unit Containers on a Flat Car Being Loaded. This shows the easy manner of loading and the method of numbering containers for quick identification

THE CONSTRUCTION AND METHOD OF HANDLING AND LOADING A SECTIONALIZED FREIGHT CAR

Standardized Containers and Sectionalized Freight Cars

By R. H. McLain

Power and Mining Engineering Department, General Electric Company

A number of articles in this issue make reference to the fact that the principal difficulty in the development of machinery for handling package freight arises from the miscellaneous character of the packages shipped. This article describes the operation of a system using standardized containers and sectionalized freight car bodies, explains how it will expedite the delivery of less-than-carload shipments and reduce to the minimum the waste inherent in the present method employed for these small lots of freight.—Editor.

There is a tremendous waste under the present system of less-than-carload shipment for small amounts of freight. This waste occurs: first, in the valuable lumber which is used for the crates; second, in the breakage of poor boxes; third, in pilferage; fourth, in the loss of stowage space in freight cars due to the odd shape and frailty of packages; fifth, in the handling expense and congestion at railway transfer points where goods are moved by hand when being transferred from car to car.

A system of transportation which will eliminate this inefficiency can be effected. Component parts of such a system are in practical operation in various places in the world at present. An assembly of these components into one super-transportation system in the United States is worthy of the combined efforts of all its citizens. In the United States about 60 per cent of the freight is carried in carload lots and about 40 per cent in less-than-carload lots. Our box cars have a rated capacity of about 40 tons each. In Europe a car or "wagon" is rated at about 10 tons, and a smaller percentage of freight goes in less-than-carload lots. It is easy to see that the smaller the car the less will be the amount of less-than-carload freight; and if the cars are made small enough, the less-than-carload freight will almost vanish. However, a smaller car, while useful in a small country where car-mileage is unimportant, clearly has no place in the United States where a car may travel several thousand miles on one trip.

The ideal arrangement is certainly a combination of the two types of carriers, whereby some four or more small detachable car-bodies are carried on one large car truck. The operation of this system will be facilitated by the use of over-head traveling cranes or locomotive cranes for transferring the small car-bodies from car truck to car truck at transfer yards; and by the use of suitable automobiles for carrying these bodies between the railway stations and the shippers' warehouses. Small hoists, operated by electric power or by hand, would be used for transferring the bodies at railway stations. By this system shippers of one-fourth of a carload lot or even less, who have no railway tracks at their plants, would have somewhere near as economical transportation facilities as does the shipper of carload lots who has railway tracks at his door.

Furniture, mail, and express are handled on the continent of Europe and in England by this system, using automobiles, boats, and railway trucks, all during one trip. This arrangement would take care of the transportation needs of shippers who can ship in lots of something like one-fourth or one-fifth of the present standard box car, and would reduce the crating expense of such shippers by a considerable amount because goods for lot shipment in a small car-body do not always need to be crated in as expensive a manner as those which are for less-than-carload lot shipment; but the arrangement does not take care of the transportation needs of the smaller shipper, nor all of the crating needs of any shipper. Substantial metal containers with "thief-proof" locks are now made in both the collapsible and the non-collapsible type. Such containers are used now by express companies and some merchants for shipping valuable goods and by a few shippers for ordinary goods. They can be made of various sizes with dimensions which fit snugly in the space available in the small car-bodies, and also can be of sufficient strength to withstand the strain of being packed at the bottom of a fully loaded freight car. At present, one trouble in using these containers for ordinary goods is that the shipper of the goods must own the boxes and must, therefore, pay freight on the return trip empty.

An ideal system would be for a giant transportation company to own enough containers to take care of the requirements of the whole

United States and to operate warehouses at all shipping points. This company could lease, deliver, and collect both empty and loaded containers at the shippers' plants. They could consolidate containers into small car-bodies so as to require that a container be shifted from one car-body to another as few times as possible during a trip. By proper management, this company could provide that railway trucks and trains are more fully loaded both as to space and weight than is possible under the present system. The small containers and small car-bodies, all belonging to one company, need make no useless trips empty, but would carry loads on practically all trips, just as railway box cars and mail pouches now cruise around the country making as many loaded trips and as few empty trips as possible. The United States Post Office Department operates very much in this manner so far as general plans and management are concerned, but on account of the character of the material handled does not need to have such large physical equipment. The economical benefits of such a system, when once it is fully organized and operating, would be tremendous; but, of course, there will undoubtedly be many painful struggles before such a system .can be put into operation.

The advantages would be a saving in boxing charges, less breakage and pilferage, the elimination of a great deal of labor in handling goods, and greater despatch because all freight would go by a system which corresponds somewhat to the despatch of carload lot shipment at present.

Imagine the operation of such a system in a city located near the middle of New York State. Suppose a householder in the residential district wishes to ship 100 lb. of miscellaneous household goods to Southern Texas. He estimates the weight and space of his goods and requests the transportation company to send a suitable box. This is delivered at his door and he makes a small deposit for the safe return of the box. When he has packed it, he again notifies the transportation company and gives the destination of his shipment. The transportation company each day circulates in the city several trucks which carry the small detachable car-bodies previously mentioned. One truck will collect east-bound goods for points west of Albany; another east-bound goods for points beyond Albany; another will collect west-bound goods for points east of Buffalo; another west-bound goods for points beyond Buffalo, etc. The proper truck will call at the shipper's door and by the time it reaches the railway station will be fully loaded with containers all of which are for points west of Buffalo. At the station, it will be sealed, taken bodily from the automobile, and lifted onto a railway truck which is going to Buffalo. At Buffalo, or some other suitable transfer point, this car-body will be broken open and the containers transferred to other suitable small car-bodies which are going to some point in Texas, as near as possible to the final destination.

At such grand centers as Buffalo, or any other suitable collection point, there would be lying in wait small car-bodies, each intended for some freight center in the United States. So far as Buffalo is concerned, the whole United States would be divided into freight zones, possibly 500 in number, and one small car-body would be designated for each of these zones. Such a car-body might require several days of waiting before it is completely filled. Then it will be sealed and shipped through with all of the despatch of a solid carload shipment to the freight center nearest the final destination in Texas. At this point, the car-body would again be broken open and the containers re-assembled into a car-body which is going to the railway station of the consignee. This last car-body, when it reaches the railway station, is filled with goods only for that particular station and is taken as a whole from the railway truck to an automobile. The seal is broken and all of the containers in this car-body are delivered to the street addresses of the consignees.

Such large shippers of miscellaneous freight as Sears, Roebuck might very well have their own zoning system for the United States and ship small car-bodies to each zone center once every three or four days. It is readily apparent to one familiar with the shipment of less-than-carload goods that far greater overall despatch is obtained by allowing goods to lie stationary for several days, or even a week, awaiting opportunity to go through as a solid carload shipment than to start them immediately on a trip as less-than-carload goods.

Preparation of Goods for Transportation and Storage

By Harry N. Knowlton

Boxing and Packing Specialist, General Electric Company

While everyone realizes that proper packing is essential to the delivery of goods in an undamaged condition, everyone is not acquainted with just what are the elements of proper packing or the influence which these have on the design of the artcles to be shipped. Mr. Knowlton outlines these factors and emphasizes the desirability of using an easily readable and uniform system of marking.—Editor.

It is common practice with most progressive manufacturers to take particular pains to prepare their goods so that they can be safely and readily transported and stored. Careful attention to this matter is necessary to the satisfactory and profitable conduct of any business. It is not generally appreciated, however, except by those in intimate touch with this phase of the business, just how important are some of the seemingly minor points in connection with proper packing, marking, and conditioning goods for shipment; and it is therefore desired briefly to mention some of these points in this article.

Effect of Design of Material on Packing and Shipping

An important angle of the problem, and one to which enough attention has not been given in the past, is the fact that in designing material for manufacture consideration should always be given to the matter of whether the design provides a good shipping proposition or, in other words, an article which can be safely shipped and stored without an excessive outlay for boxing or excessive transportation charges. The proper mechanical operation of the material is naturally of first importance and the design cannot, of course, be altered at the expense of this feature. It often happens, however, that slight changes in design which do not in any way affect the proper operation of the material will make it possible greatly to reduce the amount of lumber required in boxing or will make it possible to cut down the size of the package, thus saving transportation charges. For export shipment it is particularly necessary that the size of the package be reduced to a minimum, as in many cases the weight per cubic foot is small and the ocean freight charges are based on measurement instead of on weight. In such instances, disassembly of the material is often desirable provided that reassembly is not too difficult and complicated, and this point should be considered in its design. Oftentimes, the addition of base holes of proper strength would make it possible to bolt the material to skids, eliminating much expensive blocking in the case and providing a much more stable and secure package. In other cases, changes in the design of a bracket or other projecting part might make it possible to block the material more securely or to save several inches of space thus using a smaller container.

Shape and Weight of Small Packages

There are many features in the construction of the container and in the method of marking which make for safe and economical transportation and storage. With small package material, where a number of the same articles are boxed together, the shape and weight of the package are important. As a rule, the gross weight of the package should not exceed 300 lb., or a weight which can be conveniently handled with trucks by man-power. The shape of the package should preferably approach a cube, as a cubical box is generally the cheapest shape of box to make and the falls which it receives during transportation are much less severe and cause less damage than is the case with the long flat package.

Design of Heavy Packages for Proper Handling

Heavy packages which are handled mechanically with slings and crane must be so constructed that they can be safely handled without damage to the contents or the container and without injury to the men who handle them. The ends of skids should be slotted for the sling cable and marks should be stenciled on the package indicating the position of the slings. This is particularly important where the center of gravity of the package is considerably off center. The construction of the package should also be strong enough to withstand the crushing action of the sling cable when the package is lifted. The ends of skids should be chamfered so that the package can be easily moved about without catching on projections on the floor.

General Construction of Large Packages

In large packages, the skid and frame construction and the method of bracing the contents in the box are of much importance. The skids form the backbone of the package and must always be strong enough to sustain the load under all hazards of transportation. Where the base of the contents is not in contact with the skid over the entire length of the skid or where it is necessary that the skids project considerably beyond the contents to give stability to the package, it is particularly necessary that the skids have a large factor of safety. The sides and ends of the package should always be of sufficient strength to support the weight of other cases which may be stored on top of it in the ships hold or in the warehouse. Packages which are long in comparison with their height should always be braced vertically in the center to prevent collapse and diagonal braces should be used to prevent racking. With diagonal braces it is very important that they be placed at an angle not to exceed 45 degrees, since at greater angles than this they lose much of their efficiency. The contents should always be firmly braced against movement in any direction inside the container and braces should be so placed that they engage as many boards as possible so as to distribute the strain over a large area. Wherever possible the construction of the large package should be of sufficient strength that it will ride safely in other position than upright as there is never a certainty, even though the package be so stenciled, that it will always be handled in an upright position.

Details of Case and Crate Construction

Much of the strength of a case or crate necessarily depends upon the quality of lumber used in its construction and upon the method of fastening it together. The species of lumber used is not as important a matter except in special cases, as that the lumber be thoroughly seasoned. When green lumber is used, the container loses much of its strength when it drys out, due chiefly to the loosening of the nails. The use of hardwood often results in economy, as lumber 25 per cent less in thickness can be used owing to its greater inherent strength and greater holding power for nails and fastenings. Proper nailing is of the utmost importance as an inadequate number of nails or improperly placed nails make weak containers. Nails should always be cement coated as this type of nail has approximately 30 per cent more holding power than the plain nail. All boxes and crates for export shipment should be metal strapped, as strapping greatly increases the strength of the container. Flat band *unannealed* steel strap should be used and it is very important that the strap be stretched to maximum tension with a mechanical stretcher before nailing it onto the container. Strap which is not stretched before nailing bulges excessively between the nails when the container drys out and makes it very difficult to handle in the warehouse because the loops in the strap catch on other packages. Where bolts are used to fasten the contents to the skids, the heads should be countersunk so that they are flush with the skid bottom. When the bolt heads project below the bottom of the skid, they make it difficult properly to use rollers under the package. The threads on the bolt over the nut should be upset to prevent the nut from working loose.

Marking

Although of equal importance to packing, marking is an operation to which proper attention is often not given. Improper or insufficient marking may result in delays in transportation, delays in the warehouse, the imposition of fines by foreign Customs Houses, or even in complete loss of the package. All marks should be stenciled. Brush marks are indistinct, occupy too much space and are often illegible. The marking fluid should be strictly waterproof and of a quality that the marks will be permanent. Each mark on the package should have its special location. No other thing would be of more help to transportation men and warehouse men than if a standard marking scheme would be put into effect by all manufacturers with special reference to the location of the marks. Packages are often seen which are completely covered with marks making it necessary to turn the case over on all sides to get the required information. On export packages the two sides of the case should be reserved for the consigning marks or symbol, the port mark and the case number, no other marks being placed on these faces of the package. These marks are always written in larger letters than any of the other marks on the case as they are the most important from the transportation standpoint. On the ends of the case are placed the requisition number, and the gross and net weights; the measure and the case number are repeated. On large cases these marks are stenciled in 1¾-inch letters. The marking of smaller packages is the same as the marking of the large with respect to the location of the marks but smaller letters are used. The port marks, consigning marks, and case number on the sides are in smaller letters and the marks on the ends are stenciled in ⅞-inch letters. The marking of domestic packages is similar to the marking of those for export, except the measure and the net weight are omitted and the destination of the package takes the place of the port mark.

Bibliography on Freight Handling

By R. F. Emerson

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R. F. Emerson

It has been estimated that the cost of handling freight at the two terminals of the average length freight haul is about 50 per cent of the total transportation charge. A. H. Smith, president of the New York Central Railroad, is quoted as saying that it costs more to handle a barrel of flour in New York City than to bring it there from Chicago. The reduction of this high cost of handling freight at terminals has naturally been the object of considerable study on the part of terminal engineers and others.

Many accounts have appeared in the technical press of the manner in which Cincinnati has endeavored to solve one phase of this problem by substituting motor trucking combined with demountable freight car bodies in place of the usual wasteful method of shunting freight cars. The railroads having terminals in Cincinnati are using five-ton vehicles with detachable bodies. Two of these bodies fit an ordinary flat freight car. Detaching the car bodies loaded with goods immediately after arriving at its destination allows the car to receive two empty bodies and to be put into active use again, rather than standing idle on a railroad siding.

Furthermore, the large increase in the amount of export freight since the beginning of the European war has shown the inadequacy of our freight handling equipment at our ports. New York City with one of the best natural harbors in the world, and having more than double the water frontage of either Hamburg, London or Liverpool, is no where near as well equipped with freight handling equipment on the water-front as these European ports. That this condition is being recognized is evidenced by the fact that representatives from the Department of Docks and Ferries, together with representatives from all the leading steamship lines entering New York City, have conferred as to the very best freight handling methods to be installed for the 1000-foot pier at West 46th St., on the Hudson River; also, the harbor congestion at San Francisco has been the subject of an investigation by Miles Standish of the Harbor Commission and F. E. Boyd, Manager of the Small Motors Department, of the General Electric Company at San Francisco.

The problem of material handling is not by any means confined to railway and marine terminals. The same problems exist in many of our factories and many articles have been written on the improved results obtained in handling material in automobile factories, foundries, warehouses, rubber mills, etc., by making use of various types of conveyors, trucks, elevators, cranes, hand cars, and other devices.

The following bibliography gives a partial list of articles on the general subject of material handling that have appeared in the technical press since 1914. A short description is given after each listing, which may be of assistance to those seeking information on the subject.

1915

Three-phase Electric Cranes at the Port of Bordeaux, Anon.
Elec. Review, London, May 21st, 1915.
Describes features of the six large electric cranes installed on the Queyries Wharves.

Past, Present and Future Freight Handling, J. F. Coleman.
Pro. Am. Assoc. Port Authorities. No. 60906 N.
Questions of hand labor or machinery on wharves.

Transfer Facilities at Marine Terminals (Illus.), H. McL. Harding.
Int. Marine Engr., March, 1915, Vol. XX, No. 3, page 98.
Designs for equipment for economical loading and discharging of vessels; relative costs of different methods.

Mechanical Conveyors and Their Influence on the Development of the Country Tributary to Ports (Serial 1st part), Hans Wettich.
Zeitschrift des Vereines.
Deutscher Ingenieure, Sept. 4, 1915.
General discussion and series of examples.

The Latest Developments in the Field of Mechanical Loading and Unloading of Vessels (Serial 1st part), Curt Brecht.
Annalen fur Gewerbe und Banwesen, L. Glaser, April 15, 1915.
Description of series of new devices.

How to Make Cargo Handling More Efficient, H. M. Harding and J. A. Jackson.
Engr. Rec. Dec. 4, 1915.
General discussion as to proper equipment for terminal plants and value of educational work and investigation.

Freight Handling at Havana, Cuba, Anon.
Int. Marine Eng. March 1915, Vol. XX, No. 3, page 116.
New re-inforced concrete steamship piers at Havana equipped with efficient means for handling freight; description of two escalators.

Freight Handling at Railway Marine Terminals (Illus.), C. A. Hardy.
Int. Marine Eng., March, 1915, Vol. XX, No. 3, page 103.
Description of arrangement of steamship pier, with overhead and gantry travelling cranes for handling freight.

Marine Terminal Machinery, H. Sawyer.
Int. Marine Eng., March, 1915, page 109, Vol. XX, No. 3.
Location of cargo-handling machinery on pier vs. location on shipboard,—different types of cargo handling machinery compared—relative arrangement of adjacent freight sheds and railway tracks.

Points of Attack in the Terminal Problem (Illus.), J. A. Jackson.
Int. Marine Eng., March, 1915, page 111, Vol. XX; No. 3.
Possibilities for reduction of terminal charges for handling freight. Faults to be overcome in the existing conditions.

Possibilities Open to Central Stations in Solving the Freight Terminal Problem, J. A. Jackson.
G. E. Review, December, 1915, page 1143, Vol. 18.
Large percentage of total transportation charges is the handling charge at terminals—can be reduced by use of electrically-operated mechanical devices.

Transfer Facilities at Marine Terminals (Illus.), H. M. Harding.
Int. Marine Eng., March, 1915, Vol. XX, No. 3.
Plans and designs for equipment for economical loading and discharging of vessels at marine terminals.

Unloading Cargoes by Portable Machines (Illus.), Anon.
Int. Marine Eng., March, 1915, Vol. XX, No. 3, page 105.
Successful installation of two conveyors at Port of New Orleans for loading and unloading ships' cargoes—weight of single pieces, running from 95 to 700 lb.—varying in bulk and shape.

Electric Trucking at the N. Y. Terminals of the Southern Pacific Steampship Co., (Illus.), Anon.
Int. Marine Eng., March, 1915, Vol. XX, No. 3, page 102.
Results obtained by substitution of electric storage battery trucks for hand trucks previously used.

Reservoir Effects in Freight Movements, R. H. Rogers.
International Marine Engineering, March, 1915, page 107.
The desirability of warehouse systems at our coast cities, also cities bordering on large productive areas is emphasized because warehouses tend to smooth out the peaks and valleys of supply and demand.

The Modern Trend in American Marine Terminals, R. H. Rogers.
Paper presented before International Engineering Congress, September, 1915.
Improvements are noted in the way of winches, conveyors, cranes, industrial trucks, car pullers, automatic weighing machines, battery charging devices, etc., tending to promote safety, dispatch, economy and service.

Cargo Handling Methods and Appliances, J. A. Jackson.
Paper presented before International Engineering Congress, San Francisco, Calif., September, 1915.
Freight is classified as bulk freight, line freight, and miscellaneous or package freight. Past and present methods of handling freight are compared with suggestions for improving cargo handling methods.

The Handling of Freight in Terminals, R. H. Rogers.
Paper presented before A.I.E.E., June 29, 1915.
The principal methods used for package freight handling are storage battery vehicles such as commercial trucks of various types, monorail devices conveyors, derricks, winches and different kinds of cranes. The advantages of electric motor drive for these devices are emphasized.

1916

The Donald Portable Ship Elevator Conveyor (Illus.), G. F. Zimmer.
Engrg., Nov. 24, 1916, page 503, Vol. 102.
Designed for loading miscellaneous cargo in and out of ships.

The Development of Appliances for Handling Raw Materials and Merchandise at Ports and Other Large Centers, Sir J. P. Griffith.
Institute C. E., Oct. 24, 1916.
James Forrest, Lecture.

Continuous Package Elevators, on Philadelphia Piers (Illus.), H. J. Edsall.
Eng. News, Aug. 31, 1916, page 406, Vol. 76, No. 9.
Detailed description—power requirements—performance, etc.

Helping the Electric Stevedore (Illus.), H. C. Yost.
Int. Marine Eng., October, 1916, page 448, Vol. 21.
Practical hints for improving the service of industrial trucks, tractors and trailers at steamship piers.

Status of Cargo Handling in American Marine Terminals, J. A. Jackson and R. H. Rogers.
G. E. Review, February, 1916.
Discussion of various types of mechanical devices for handling (1) bulk freight, (2) live freight, (3) miscellaneous package freight.

How Electricity is Harnessed to Terminal Work, R. H. Rogers.
Published in International Marine Eng., October, 1916.
Moving freight by electricity—source of the power—generator, transformers, motors and control devices—methods of braking storage battery trucks.

Portable Machinery for Package Freight Handling, R. H. Rogers.
G. E. Review, June, 1916.
Author points out the great variety of shapes, weights and dimensions in which package freight comes to terminals, piers and warehouses. The adaptability of various mechanical devices to meet these various requirements is discussed.

Selection of Electrical Apparatus for Cranes, R. H. McLain and J. A. Jackson.
G. E. Review, June, 1916.
Different classes of service for which cranes might be used, methods and examples of figuring horse power of crane motors—description of electrical control equipments.

Mechanical Equipment Used in the Port of New Orleans (Illus.), William Von Phul.
A.S.M.E. Journal, July, 1916, Vol. 38, pages 515–528.
Gives descriptions of various methods of handling the different kinds of freight which come into the port of New Orleans.

Competing Marine Terminals at Seaports, H. McL. Harding.
Int. Marine Eng., October, 1916, Vol. 21, page 455.
Sea-ports must provide better terminal facilities, such as transferring and handling machinery—lessons from European cities.

Portable Loading and Unloading Machines for Marine Terminals (Illus.), Harwood Frost.
Int. Marine Eng., October, 1916, Vol. 21.
Application of "Brown-Portable" machines to wide variety of uses in loading and unloading package freight.

Motor Trucks at Steamship Terminals, H. C. Hutchins and H. W. Perry.
Int. Marine Eng., October, 1916, page 441.
Average saving of over 36 per cent in ton-mile cost of handling with motor vehicles—other benefits.

Freight Handling Through Unoccupied Terminal Space (Illus.), S. H. Libby.
Int. Marine Eng., October, 1916, Vol. 21, page 459.
Utilization of hitherto unused or waste space over storage piles for mechanical transference of freight.

The Economics of Material Handling in Manufacturing Plants, Reginald Trantschold.
Industrial Management, Vol. 52, page 231, November, 1916.
Analysis of speed, capacity, costs and depreciation charges of elevating and hoisting conveyors with charts showing their various relations.

1917

Telphers and Transporters, George Frederick Zimmer (Illus.)
Elec'n., December 14, 1917 (Special Number).
Compares merits of telphers and conveyors, describes types of telphers in use and performances that may be expected.

30-ton Electric Traverser, Moor Street Station, G. W. R. Birmingham, Illus. and Plate.
Engineering, March 9, 1917, Vol. 103, page 222.
Detailed description, method of driving—capacity results of tests.

Handling Materials (Illus.), Anon.
Iron Age, Feb. 22, 1917.
Contrivances for conveying and for storing.

The Equipment of Railway Goods Stations with Electrical Machinery for Dealing with General Merchandise (Illus.), Roger T. Smith.
Elec'n., Dec. 14, 1917. Vol. 80, No. 11, page 376.
Considers electricity superior to any other motive power, examples given of cranes, capstans, conveyors, traversers, etc., used in four modern stations of the Great Western Railway.

The Present Day Handling of Our Foodstuffs by Machinery, Anon.
Elec'n, Dec. 14, 1917 (special number), Vol. 80, page 388.
Examples of the conveyor applied to handling important foodstuffs.

The Modern Cargo Crane (Illus.), Claude M. Toplis.
Electrician, Dec. 14, 1917, Vol. 80, page 410.
Relative advantages of the electric, steam and hydraulic types. Typical designs briefly given.

Handling Freight on New York's New Steamship Pier, C. W. Stamford.
Engr. News-Record, Vol. 79, Dec. 6, 1917, page 1058.
Equipment details for 46th St. wharf on Hudson River. Plans of upper and lower floors of piers are shown, indicating freight handling layout.

Time Savers in Handling Material, William P. Kennedy.
Ind. Management, March, 1917.
Devices such as demountable bodies, dumping bodies, trailers, portable elevating devices, cranes, conveyors, etc., that enable motor trucks to do effective work.

Handling Freight in Shipping and Store Rooms (Illus.), Horace Goldstein.
Ind. Management, July, 1917, Vol. 53, page 529.
Describes freight handling machinery for storerooms, first for storing or tiering, second, for lowering and elevating, and third, for transferring considerable distances.

Factory Transportation (Illus.), Edward K. Hammond.
Machinery, July, 1917 (Serial, 1st part).
Reviews existing methods of moving work in the factory.

Electric Trucks—A Remedy for Terminal Freight Congestion (Illus.), Anon.
Elec. World, April, 1917, Vol. 69, No. 15, page 692.
Enormous off-peak load in battery trucks available to central stations. Bush Terminal, N. Y., uses 12,000,000 kw-hr. annually.

Handling of L. C. L. Freight in Warehouses and on Platforms of the M. K. & T. Rwy., Anon.
Railway Review, Sept. 1, 1917, Vol. 61, No. 9, page 255.
A critical review of facilities and methods—"drop truck" system of handling recommended in place of "gang" system.

Using Electric Lift Bridges to Reduce Trucking Distances on Freight Platforms (Illus.), Anon.
Sci. Am., Feb. 10, 1917, page 157.
The Atchison, Topeka & Santa Fe Railroad at Los Angeles uses lift bridges to transport packages from one platform to another over intervening tracks.

Waterway Transportation for General Electric Co. Traffic (Illus.), R. H. Rogers.
G. E. Review, June, 1917.
Possibilities of waterway transportation between plants of the General Electric Co.—includes plans of a suitable boat. Importance of terminal facilities is emphasized.

Handling Freight Faster with Fewer Men, F. C. Myers.
Rwy. Age Gazette, Dec. 7, 1917, Vol. 63, pages 1039–1042.
By using electric trucks, one road moved 60 per cent more freight with 42 per cent less labor.

The Electric Vehicle as a Load for the Central Station, C. A. Rohr.
G. E. Review, May, 1917, page 377.
Article points out that the use of the electric vehicle means off-peak business and table is given showing annual income per kilowatt of plant equipment for 2-ton electric truck compared with other installations.

1918

Typical Mechanical Handling of Miscellaneous Articles (Illus.), A. B. Proal, Jr.
Industrial Management, Vol. 55, June, 1918, page 453.
Gives typical installations for handling classified material. No conveyor is capable of handling all kinds of goods.

How to Move Materials by Machinery (Illus.), Henry J. Edsall.
Industrial Management, July, 1918, Vol. 56.
Applications of various types of elevating and conveying machinery to load, unload and transport various materials in industrial plants.

Driving Power Required by Conveyors of Various Types, R. F. Muirhead.
Car Eng. Monthly, August, 1918.
Power required to transmit material between given terminals and power consumption.

Bridge Motors for Overhead Travelling Cranes, R. H. McLain.
Am. I.S.E.E., September, 1918.
Rules for selecting the proper size motor and gear ratio for bridge motion.

How Freight Handling Machinery is Being Used Abroad, Harry Varndell.
Engr. News-Record, Vol. 80, pages 713–715, April 11, 1918.
An illustrated article describing portable elevator-gravity roller stacking machines, etc., now being used, due to scarcity of labor.

Handling Freight on Inland Waterways (Illus.), H. McL. Harding.
Int. Mar. Engr., Vol. 23, No. 12, December, 1918, page 667.
Advantages of effective inland terminals—operating costs small—importance of mechanical methods.

Conveyor Scheme for Handling, N. Y. City's Package Freight (Illus.), Anon.
Rwy. Age, Sept. 6, 1918, Vol. 65, No. 10, page 455.
Suggested layout of warehouses, piers and conveyors on New York and New Jersey sides of the river.

Freight Handling in the Panama Canal (Illus.), Anon.
Int. Marine Eng., January, 1918.
Introduction of storage battery trucks in 1915 revolutionizes methods—operating costs.

Plan Proposed to Relieve Freight Congestion in New York, Anon.
Elec. Rev., Feb. 16, 1918, Vol. 72, No. 7, page 300.
Conference between railroad managers and city business men results in a plan put forward for using city's trucking facilities for handling L. C. L. freight—railroads to deliver L. C. L. freight at warehouses immediately instead of holding for consignee's pleasure. Plan has worked well in England.

Electric Cargo Winches (Illus.), E. F. Whitney.
G. E. Review, February, 1918.
Duty of cargo winches defined. Electrically operated winches are superior to steam operated winches in meeting these requirements.

Electric Tractors and Trucks in Freighthouse Service, Anon.
Railway Review, February 16, 1918, Vol. 62, No. 7, page 245.
Competitive tests between hand trucks and electric trucks in handling package freight—different types of trucks and tractors are compared.

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The Mechanical Handling of Materials, P. G. Donald.
The Electrican (London) Jan. 10, 1910, page 29.
The excuses given by firms for not adopting mechanical handling generally takes the form of (1) no room, (2) insufficient power, (3) the works are too old. After discussing these objections, the author deals with the value of such plant as an investment, the speed that is desirable, the importance of a suitable layout, etc.

Port Facilities and Freight Handling, Anon.
Journal of Electricity, April 1, 1919.
A rough outline of a possible plan for improving San Francisco's harbor to meet expanding commerce in peace times, includes an increase in efficiency through the adoption of mechanical freight handling facilities.

The Gravity Roller Runway, G. F. Zimmer.
The Electrician (London), Vol. 82, Jan. 10, 1919, page 33.
The author deals in some detail with the component parts of roller runways, also illustrates spiral chutes, portable humpers, stackers, "gadgets," etc.

Electrically Operated Dock Cranes, Anon.
Journal of Electricity, Vol. 43, Oct. 15, 1919.
Article gives principal dimensions, speeds and capacities of four semi-portal bridge type wharf cranes, furnished by Wellman-Seaver-Morgan Co., for U. S. Army Supply Base, Boston.

Labor Substituted by Electric Truck in Warehouse, D. L. Darnell.
Electrical Review, Sept. 13, 1919, page 441.
Two general systems, the tractor with trailers and the load-carrying truck are suggested for application to warehouse installations.

Electric Trucks and Tractors in Printing Plants, Bernard J. Dillon.
Electrical Review, Nov. 29, 1919, page 896.
The advantage of this class of apparatus in printing plants is considered, also methods of applying electric apparatus to the handling problems of such plants.

Shipments Handled by Electrical Auto-mechanical Equipments, Zenas W. Carter.
Electrical Review, Dec. 6, 1919, page 939.
How electrical equipment can and is already solving the freight terminal problem. The Gattie system in London-Cincinnati experience.

Port Facilities and Freight Handling.
Journal of Electricity, Vol. 42, April 1, 1919.
Extracted from report for San Francisco Chamber of Commerce, describing methods of improving congested freight conditions in San Francisco harbor, to meet expanding commerce by means of mechanical freight handling devices.

Industrial Electric Trucks and Tractors in Machine Shops, Bernard J. Dillon.
Electrical Review, Vol. 75, Oct. 25, 1919.
Illustrating various applications to hauling materials around shop and lifting them on to machines.

Motor Trucks and the Problem of Efficient Marine Freight Terminal Operation, I, II, III., Merrill G. Horne.
Int. Marine Eng., Vol. 24, Nos. 8, 9, and 10, August, September and October, 1919.
August—Discussion of inter-relation of railroads, transfer drays and steamships with piers and warehouses.
September—Comparison of horse dray with motor carriers, also discussion of value of store-door delivery.
October—Emphasizes that weak link of our transportation facilities as applied to overseas commerce is not in railroads or ocean carriers, but in methods and facilities employed for handling freight at marine terminals.

Use of Industrial Electric Trucks and Tractors in Warehouses, Bernard J. Dillon.
Electrical Review, Vol. 75, No. 9, August, 1919, page 345.
Application of such equipments to handling problems of warehouses and storage places of all types—difficulties encountered in application—analysis of handling operations.

Use of Industrial Electric Trucks and Tractors by Railroads, Bernard J. Dillon.
Elec. Review, Vol. 74, No. 26, June 28, 1919.
Methods of application in handling freight and baggage—methods of application—difficulties encountered in operation.

Industrial Electric Trucks, Tractors and Narrow Gauge Locomotives, Raymond J. Mitchell
Elec'n., Vol. 82, No. 2121, Jan. 10, 1919.
Conditions under which electric trucks are to be desired—rapidity with which goods may be handled—main features of electric trucks now on the market—results achieved at the Mantua Transfer Station of the Pennsylvania Railway.

Light as an Aid to the Transportation of Material, A. L. Powell and R. E. Harrington.
Trans. Illum. Eng. Soc., Vol. 14, No. 1, Feb. 10, 1919.
Article states that proper lighting of stations, warehouses and piers increase their capacity, which in turn depends on speed with which material moves through them.

Electric Truck as a Means of Shop Transportation.
Con. Mchy., Vol. 21, No. 5, Jan. 30, 1919.
Illustrates uses of electrical storage battery trucks in industry for automatic transportation in loading and unloading ships and railway cars, and in the machine shop, tire factory, textile mill and electric wire insulating and manufacturing plants.

Coming Mechanical Devices that Will Make Shiploading Economical, Anon.
Int. Marine Eng., June, 1919.
Modernizing port and harbor terminals by crane hoists, overhead telpher systems, electric tractors and trailers.

Construction of St. Louis Municipal Wharf, Anon.
Railway Review, Feb. 22, 1919, Vol. 64, No. 8, page 275.
Mainly a description of the construction of North Market Street Municipal Wharf. Brief reference made to cranes, elevators and conveyors, which are to be installed.

Modernizing Freight Handling Methods, B. K. Price.
Iron Trade Review, Aug. 7, 1919.
Distinction is made between bulk freight and package freight and advantages pointed out of moving latter by means of various mechanical appliances.

Radical Departure in Loading Ocean Freighters (Illus.), Anon.
Railway Age, April 18, 1919, Vol. 65, No. 16, page 981.
Erie Railroad utilizes existing equipment in handling 50 locomotives direct from pier to ship.

Reducing Cost of Handling Freight (Illus.), Anon.
Railway Review, March 22, 1919, page 453.
The Orange Ave. Freight Terminal of the N. Y. C. R. R. in Cleveland, is operated on a basis designed to reduce cost and time expenditures. This scheme of operation is made possible through the use of labor saving equipment in conjunction with a scheme of routing that permits the utilization of this equipment to the fullest possible advantage.

Use of Electrical Equipment on San Francisco Water Front, C. W. Geiger.
Elec. Review, June 14, 1919, page 977.
The congested condition of piers necessitates the adoption of industrial electric trucks, tractors, conveyors and piling machines—description of installations—methods of operating.

Stacking Device Simplifies Freight Handling (Illus.), Anon.
Eng. News, Nov. 13, 1919, page 855.
A short article describing a self-driven electrical machine developed at Seattle, for lifting heavy bales and boxes (1400 to 2000 lbs.) into place at low cost.

Speed Control of Induction Motors on Cranes and Hoists by Means of Solenoid Load Brakes and Multiple Magnet Brakes, R. H. McLain and H. H. Vernon.
G. E. Review, Feb. 1919.
Mechanical load brakes, electrical braking, solenoid brakes, and multiple magnet brakes are defined and methods of their operation with revolving hammer head cranes, gantry cranes, etc., are described.

What Freight Handling on Electric Roads Requires and Costs (Illus.), by A. B. Cole
Electric Rwy. Journal, Feb. 1, 1919, Vol. 53, pages 219–228.
Points out need of adequate freight terminals, and mechanical freight handling devices. Valuable operating data are given for freight houses.

Electric Trucks and Tractors in the Iron and Steel Industry (Illus.), by B. J. Dillon.
Electrical Review, Vol. 75, No. 13, page 518.
Advantages of industrial electrical apparatus in smelting plants, foundries, etc.

Electric Trucks and Transportation, E. E. La Schum, Gen'l Supt. American Rwy. Express Company.
Advantages of the electric truck and comparisons with other vehicles. Operating data of American Rwy. Express Company.

Electricity as Applied to Loading and Unloading Coal and Ore Boats, R. H. McLain.
General Electric Review, May, 1919, page 352.
This paper reviews briefly the history of the development in unloading boats, gives a summary of modern methods of electrification and finally describes a number of loading plants.

Car Dumpers, J. A. Jackson.
General Electric Review, May, 1919, page 366.
Two general types of car-dumpers are mentioned, side-dump type and end-dump type. The former type, which is more generally used in this country, is described together with methods of operation. Load curves, speed-torque curves of motors, wiring diagrams, etc., are shown.

Machinery to Help Solve the Problem of High Wages, Labor Shortage and Shorter Hours Demand, Zenas W. Carter.
Manufacturers Record, Sept. 11, 1919.
A number of instances are cited where different manufacturers and cities are making use of labor-saving material handling devices, together with savings effected in time and expense.

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Freight Handling Equipment at the Port of Seattle, G. F. Nicholson.
Engr., Jan. 1, 1920, page 37.
A general description of electrical tractors, cranes, conveyors, elevators, chutes, derricks, etc., which have been installed.

Shuntless Freight Terminal, Anon.
Sci. Am., Jan. 10, 1920, page 42.
A. W. Gattie, English engineer, proposes to abolish 74 stations in London and have a single control station with electric truckers, supplemented by containers and a fleet of 5000 motor trucks.

Lightening the Stevedore's Load, C. W. Geiger.
Sci. Am., March 13, 1920, page 267.
A short article illustrating the advantages of the slung gang-plank with conveyor, over the old hand-truck method.

Appalachian Corporation of New Orleans Plans $100,000 Conveyor System to Minimize Handling Costs (Illus.), Anon.
Distribution and Warehousing, May 1920, Vol. 19, pages 46–47.
Brief description of proposed $100,000 conveyor system—capacity 36 tons per hour.

Motor Truck and Railroad Freighting, W. J. L. Banham.
Distribution and Warehousing, April, 1920, Vol. 19, pages 49–50.
Considers the extent to which motor trucks can be operated in competition with short-haul freight movement. Relative costs given.

Linking Warehouse and Railroad by Motorization, Anon.
Distribution and Warehousing, April, 1920, Vol. 19, pages 25–30 and 35.
What Cincinnati has done in reducing cost of transferal of goods on special motor trucks with detachable bodies instead of shunting freight cars.

Profit-making Fundamental of Terminal Warehousing is Reduction of Handling Charges (Illus.), Anon.
Distribution and Warehousing, May, 1920, Vol. 19, pages 30-33.
How the East Waterways Dock and Warehouse Co. reduce handling charges by use of mechanical freight handling devices.

How Electricity Helps Solve the Package Freight Handling Problem (Illus.), F. T. Smith.
Int. Marine Eng. January, 1920, Vol. XXV, page 1, No. 1.
"It costs more to load a box of canned goods on a car at Chicago, than it does to carry it from Chicago to New York." New electrical devices described, which will reduce handling charges.

Motorizing Railroad Terminals (Illus.), B. F. Fitch.
Sci. Am. Monthly, May, 1920, page 448.
The use of motor trucks releases box cars held up at freight yards. (Paper read at the Convention of the Materials Handling Machinery Manufacturers Association, N. Y., Feb. 26, 1920).

Electric Auto-mechanical Freight Handling, Zenas W. Carter, Sec'y, Material Handling Machinery Mfgrs. Association of N. Y.
Railway Review, Feb. 21, 1920, page 282.
The Gattie system in London and the Cincinnati scheme are outlined as typical installations, illustrating uses of mechanical devices for solving freight congestion difficulties.

Improvements in Bulk Cargo Handling, Anon.
The Iron Age, Aug. 12, 1920, page 385.
A short illustrated article describing a 15-ton bucket automatic ore unloader for the Lehigh Valley Railroad Company, making a complete cycle in 50 seconds; also a 100-ton car dumper for the Western Maryland Railroad.

Saving Time in Loading Motor Trucks, Joseph Brinker
Popular Science Monthly, September, 1920, page 34.
A popular article with illustrations, showing how the loading of trucks at department stores is facilitated by mechanical devices, such as belt conveyors, sorters, spiral chutes, etc.

San Francisco Develops as a Coaling Station, Chas. W. Geiger.
Coal Age, Vol. 18, No. 9, Aug. 26. 1920, page 445.
Newly installed barges can deliver coal at the rate of 150 tons per hour. The labor of coaling is reduced to a minimum by the design of barges to fit clam shell operation.

The World's Largest Crane, Anon.
Scientific American, Aug. 21, 1920, page 178.
Article describes 350-ton crane installed at the Philadelphia Navy Yard.

New Truck to Save Space, Time and Man Power, Anon.
Chem. & Metallurgical Engineering, Vol. 23, No. 7, Aug. 18, 1920, page 296.
A short illustrated article describing a new industrial truck put out by the Lakewood Engr. Co., Cleveland, Ohio, which combines the function of a tiering machine with those of a load carrying storage battery truck and is called "Tier-Lift." It can elevate a two-ton load 76 inches.

Bulk-cargo Handling on the Atlantic Coast, H. N. Turnbull
Coal Age, Vol. 18, No. 8, August 19, 1920, page 394.
One installation will transfer 30 to 45 cars per hour to ship's hold by lifting the car, inverting it, and delivering coal to chutes. Another installation will unload nearly 800 tons per hour, from the hold of the ship delivering it into cars.

Quays More Economical Than Piers for Comprehensive Port, Capt. F. T. Chambers.
Engineering News-Record, Vol. 85, No. 12, Sept. 16, 1920, page 556.
The advantages of a quick turn-around is shown by estimating overhead, port and salary charges on a ship of moderate size. Quick turn-around is made possible by use of electrical appliances such as gantry cranes, use of burtoning method, etc. Typical development of a quay layout for a port is shown.

Direct Current Crane Controllers, H. D. James, Westinghouse Elec. & Mfg. Co.
The Electric Journal, Sept. 1920, page 380.
Advantages and disadvantages of different types of controllers, such as hand type, magnetic type, etc., are compared.

The Cost of Inefficiency at our Terminals, Harwood Frost, Pres., Brown Portable Machinery Co.
Marine Engr., Sept., 1920, page 768.
Mr. Frost points out a waste of $400,000,000 yearly at our terminals due to inefficient equipment and methods.

What Should be the Dimensions of a Shipping Pier, H. McL. Harding.
Engineering News-Record, Vol. 85, No. 24, Dec. 9, 1920, page 1119.
An engineering inquiry into the size of piers and ships for various classes of ports and service covers (1) Inland River Barge Piers, (2) Inland River Ship Piers, (3) Great Lakes Piers, (4) Ocean Ports.

A Unit System of Freight Transportation, C. N. Winter.
Scientific American, Dec. 11, 1920, page 595.
Article describes containers of 10-ton capacity as adopted by the U. S. Railroad Administration in inter-water-rail transport on the Warrior River, in the New Orleans district for handling war supplies. Five of these containers fit a flat car.

How Coal is Handled in South Africa, Anon.
Coal Age, Vol. 18, No. 24, Dec. 9, 1920, page 1178.
Coal is placed in 10-ton containers, 5 of which are placed on one flat car by crane. At receiving station containers can be removed by crane.

Mechanical Handling of Gravel or Broken Stone, Alan M. Jackson.
Engineering World, Dec., 1920, page 433.
Paper before conference of County Road Superintendents and Engineers shows that slot, elevator and bin method proves very successful. Cost of outfit was saved in one season.

Material Handling Machinery, William Schack.
Paper, Nov. 10, 1920, page 190.
A consideration of the devices used in handling the raw materials as well as the finished pulp and paper so as to avoid loss of time and waste of labor.

St. Lawrence Waterway Project, from Bulletin of Chamber of Commerce, New York City.
Engineering World, Dec. 1920, page 413.
New York's "Pros and Cons" are set forth.

Construction Criticism of New York's Port Problem, Anon.
Engineering News-Record, Vol. 85, No. 26, Dec. 23, 1920, page 1241.
Article quotes an abstract from B. F. Cresson's paper entitled "An Analysis of New York's Port Problem," delivered Dec. 15 before New York Section of Civil Engineers, and then quotes from the discussion, giving opinions from Pacific Coast, Philadelphia, Montreal and also a railroad viewpoint.

The World's Largest Boilers, Anon.
Power, Vol. 52, No. 21, Nov. 23, 1920, page 828.
A short article describing 8 boilers of the Ford plant at River Rouge, Mich. States that 1000 tons of coal are consumed daily and from the time the coal leaves the Ford mines in West Virginia and Kentucky, until it is carried away as ashes, it is never handled manually. All the operations are done mechanically, dumping, pulverizing, carrying to the bins, stoking and carrying ashes away in small dummy cars.

Better Port Terminals to Develop Nation's Commerce. Abstract from paper by Col. W. J. Wilgus.
Engineering News-Record, Dec. 30, 1920, page 1292.
The fundamental requirements of piers for ports are set forth, and pier width is mentioned as of special importance.

Baltimore's Port Development Policy, Anon.
Engineering News-Record, Dec. 30, 1920, page 1293.
The Port of Baltimore has $10,000,000 immediately available for building of new piers. The port Development Commission of Baltimore has adopted nine general requirements which are set forth in this article. The fourth general requirement reads:
"To obtain expeditious movement of cargoes between land and water carriers and a maximum of economy by constructing piers large enough to hold the full contents of vessels which can tie up to them and by making proper provision for the installation of mechanical appliances and facilities to move these contents to or from the piers with the least possible delay to vessels."

Demountable Bodies Will Keep Your Truck Moving, by Joseph Brinker.
Popular Science Monthly, Nov., 1920, page 38.
Typical examples accompanied by illustrations are given showing how various concerns make use of demountable truck bodies, and thereby cut costs and reduce the number of trucks necessary. Methods of transferring truck bodies are shown.

The Electrician of Dec. 31, 1920, is known as the "Fourth Annual Materials Handling Number." A resume of the contents of this paper is as follows:

Coal Handling in the Power House, page 6, G. F. Zimmer.
A description is given accompanied by diagrams of the conveyors in the British Cellulose and Chemical Manufacturing Company's plant.

The Advantages of Mechanical Handling, page 9, E. Reed.
A number of different types of chutes, gravity runways, belt conveyors, bucket elevators, etc. are described.

Electrical Grab Transporters for Han-Yeh-Ping, page 14, H. J. Smith.
The Han-Yeh-Ping Iron and Coal Corporation is the largest industrial undertaking in China, employing about 23,000 persons. Until recently the work of unloading 3000 tons per day of raw material was done by coolies, but it was finally decided to be more economical to do this by mechanical means. A description of the material handling equipment follows.

Toplis Horizontal Luffing Cranes for the Royal Albert Dock Extensions, page 17, C. T. Pearce.
Mast type of cranes being built by Messrs. Stothert and Pitt, Ltd., for the Port of London Authority, is described. Maximum load is 3 tons at radius of 60 feet to 20 feet. Height of lift above quay level at 60 feet radius is 70 feet.

Ferro-Concrete Silos and Storage Bunkers, page 20, W. Noble Twelvetrees.
A number of typical types of grain silos, coal bunkers, stone bunkers and miscellaneous bunkers are described.

New Cranes at the Tilbury Docks, page 24, A. W. Campbell.
The development of the electric wharf crane is traced and a few unique examples of cranes and controls are cited.

Pneumatic Intake Plant for Road or Water Borne Grain, page 26, M. Jennings.
A flour mill installed at Messers. Humphries and Bobbets, Castle Flour Mills, Bristol, is considered. Diagrams and illustrations show the general arrangement of the penumatic intake plant.

The Elevator System and Grain Production, page 30, James Whitaker.
A general discussion of grain elevators, also sources of grain supply is given.

The Blaisdell Distribution, page 31, W. A. Harris.
A description of a particular type of conveyor applied to storage problems is given.

Modern Ropeway Transport, page 34, R. Kendall.
Several cableway installations are described.

The New Unloading Installations of Port of Bordeaux (In French), Henry Martin.
Genie Civil, Vol. 77, No. 1, July 3, 1920, page 1.
Details of travelling cranes are given (Eng. Index).

New Grain Unloading Saves Time at Elevators.
Railway Age, Vol. 69, No. 3, July 16, 1920, page 93.
Device said to open car doors without injury or loss of time (Eng. Index).

Portable Stacking Elevator, Anon.
Marine Engineering, Oct. 1920, page 845.
Description is given of device for elevating gunny bales weighing 1400 to 2,000 lbs. designed by Nicholson and Whitestone for use at Port of Seattle.

Production Speeding Machinery, Anon.
Industrial Management, Illustrated, Sec., Oct. 1920, page 12.
Material handling methods in the Match Industry and Steel Industry, also in coaling steamships, handling scrap iron and handling material in the storehouse are illustrated.

Labor Saving Machinery Expedites Handling Automobiles at San Francisco for Export Shipment, Charles W. Geiger.
Distribution and Warehousing, Oct., 1920, page 30.
The sequence of operation in handling automobiles from train to steamship at the port of San Francisco is described. Fewer men are required for this work now than formerly, due to new methods and new mechanical appliances.

New York's Freight Handling Problem, Anon.
Engineering News-Record, Vol. 85, No. 18, Oct. 28, 1920, page 856.
Extracts from paper presented before A.S.C.E. by Charles D. Hine, Erie R.R., points out impossibility of enlarging internal freight yards or steamship piers and urges expediting the short haul in small units and expansion of segregated groups of warehouses at numerous points rather than a few warehouses of unwieldy size.

Conveyors Speed Delivery of Sacked Coffee to Ships, S. T. Henry.
Engineering News-Record, Vol. 85, No. 16, Oct. 1920, page 757.
Installation at Port of Santos, Brazil, has capacity of about 3000 sacks per hour. Conveyors belt transport sacked coffee from warehouses to steamer decks, 280 to 360 feet distant.

Freight Handling and the High Cost of Living. An editorial.
Scientific American, Oct. 21, 1920, page 420.
Author quotes instances where cost of transfer of freight greatly exceeds cost of handling it between terminals. Use of mechanical aids in freight are advocated.

Adapting Motor Truck to Railroad Terminal Expansion, Anon.
Engineering News-Record, Vol. 85, No. 17, Oct. 21, 1920, page 785.
L. C. L. Terminal costs represent 60 per cent of the revenue. Use of trucks at Cincinnati terminals is described, and future possibilities of this system discussed.

Engineering Features of the St. Lawrence Waterway, Anon.
Engineering News-Record, Vol. 85, No. 17, Oct. 21, 1920, page 786.
A preliminary outline of the work to be done on the proposed Great Lakes to Ocean route is given.

What the Government is Doing to Help Port Layout, Anon.
Enginnering News-Record, Vol. 85, No. 18, Oct. 28, 1920, page 84.
This article quotes from a paper or report by Capt. F. T. Chambers giving details of information collected by the Shipping Board and War Department. These two organizations were authorized by the recent "Shipping Act" to look after port development.

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Containers the Ultimate Answer. Abstract from address by Col. J. C. Bonner.
Electric Railway Journal, Jan. 29, 1921, page 219.
By the use of numerous containers fixed on four wheels wagon type of 5 or 8 tons capacity it is proposed to increase the "use-efficiency" of the freight car.

Mechanical Loader Developed, 1920, G. F. Dillig.
The Coal Industry, Jan. and Feb., 1921, page 72.
Describes one of the more recent developments in mechanical coal loading machines and proving that loading is out of the experimental stage and has become remunerative.

Marine Terminals and Port Facilities, F. T. Smith.
Marine Engineering, Jan. 1921, page 66.
Past and prospective port developments in New York City, Portland, Me., Baltimore, Seattle, and other cities are discussed.

Simple Methods of Moving Materials, H. J. Edsall.
Factory, Jan. 1, 1921, page 114.
A short article describes how the Dill and Collins Company receives pulp wood by barge and finally transfers it to the pulp wood pile by successive operations by locomotive crane, electric locomotive drawing 4 or 5 cars and a log stacker. Actual saving in dollars by use of log stacker is tabulated.

Economies in Handling Materials in Industrial Plants, J. S. Tuthill.
Electrical World, Jan. 22, 1921, page 201.
This is a short article giving instances of savings by use of various labor saving devices such as electric truck handling bales of cotton, overhead trolley system in warehouse, etc.

Crane Installation at Barge Canal Terminal Handles Cargoes Quickly, Henry Cunningham.
The Marine News, Feb., 1921, page 225.
An interesting installation of two Shaw Overhead Wharf Cranes at Pier 6, East River, New York, State Barge Canal Terminal is described. Formerly it required eight men with whip boom, block and tackle and a horse, four days, to unload a barge of 175 tons of freight. Present method requires one crane operated by two men working one 8-hour day.

Better Freight Handling Methods by Mechanical Equipment, O. W. Stiles.
Engineering News-Record, Jan. 27, 1921, page 151.
Mechanical handling equipment is considered as being in three general classes, portable, semi-portable and stationary. It is pointed out that the design of a complete and efficient mechanical freight handling system requires much specialized knowledge not possessed by the average engineer. The economy of the use of tractors and trucks at various places is mentioned.

New Orleans Pushing New York for First Place in Grain Export Race, Anon.
The Marine News, Feb., 1921, page 101.
Mr. Folse is quoted as saying that "its because of the efficient grain handling terminals we have in New Orleans" that this port is now less than a million bushels behind the metropolis.

New Orleans Port to be Reorganized; Private Capital Will Aid in Development, H. H. Dunn.
The Marine News, Feb., 1921, page 148.
Plan provides for allowing corporations to obtain long-time leases on publicly owned lands to erect wharves, terminals, cargo handling equipment, etc. Revolutions by the Association of Commerce suggest that the Dock Board employ competent terminal engineers and port economists to make a thorough survey of the port and its needs.

Handling Lumber on a Large Scale, Baldy.
The Wood Worker, Feb., 1921, page 32.
A standard layout showing arrangement of planing mill, lumber sheds, saw mill, gantry and crane tracks is shown, suitable for large production.

Terminal Facilities to Increase Foreign Trade, G. F. Nicholson.
Journal of Electricity and Western Industry, Feb. 1, 1921, page 126.
Author shows that the cost of handling cargoes in Seattle is greatly reduced by the full use of mechanical equipment such as locomotive cranes for heavy work, and specialized machinery such as overhead telphers, monorail systems, etc., for miscellaneous freight.

A Carrier for Every Job, Anon.
Factory, Feb. 1, 1921, page 317.
A description is given of the auxiliary system of conveyances of the General Electric Company, for handling materials with minimum of waste in time and energy.

Electrifying Facilities Port Operation, Commander C. S. McDowell, U.S.N.
Electrical World, Feb. 12, 1921, page 365.
A description is given of some types of electrical equipment, which have made possible a reduction in port delays.

Operating a Modern Freight House Efficiently, W. E. Phelps.
Railway Electrical Engineer, Feb. 1921, page 71.
House and track arrangement, handling of freight, etc., at the New Orange Avenue freight house of the New York Central at Cleveland, is described.

Panama Canal Facts, Anon.
Scientific American, Jan. 22, 1921, page 70.
Explanation assisted by diagrams shows how Panama Canal saves time and distance, also facts and figures regarding dimensions of the canal and ships which use it.

Economical Transportation on the New York State Canal—I, Julius Kuttner.
Motorship, March, 1921, page 199.
This is the first of a series of exhaustive articles on the New York State Barge Canal. This series will constitute a study of the canal facilities and methods of propulsion, etc.

This Loader Runs on the Coal Bottom and Does Not Use the Mine Tracks, G. F. Dilling.
Coal Age, Vol. 19, No. 2, Jan. 13, 1921, page 63.
The Dilling tractor loader rams itself under the coal to be loaded. Only one machine has been built but new models are being constructed by the Dravo Contracting Company. Machine is 21 ft. long, 4 ft. 6 in. high, 46-in. gauge, weight, 11,000 lbs.

MISCELLANEOUS BOOKS, ETC.

Motor Transportation for Rural Districts, J. H. Collins.

Transportation, The Great Problem, W. J. Carter, '18, Allied Press, No. 18, Nassau St., New York City.

Ports and Terminal Facilities, R. S. MacElwee, '18, McGraw.

Transportation, Commerce, Finance and Taxation, Supt. of Documents, Washington, D. C.

Transportation of Supplies for the Army, R. E. Shannon, Quartermaster General of the Army, Washington, D. C.

Principles of Ocean Transportation, E. R. Johnson and Huebner, '18, Appleton.

More Efficient Plan for the Handling of L.C.L. Freight on the Pennsylvania Railroad Company, '17, Pennsylvania Railway Co., Philadelphia, Pa.

G. E. Bulletin No. 48,026, Electrical Equipment for Coal, Ore, and other Bulk Material Handling Machinery at Docks, R. H. McLain.

For a more complete list of Foreign Publications, American Books, Pamphlets, Addresses, Speeches, Official Reports on Ports and Terminals, Official Documents other than Reports, and publications furnished by private firms, see book by Dr. Roy L. MacElwee, Ph.D., published by McGraw-Hill Book Company, Inc., 1918, pages 304-5-6-7-8-9.

The Lighting of Piers and Docks

By H. E. Mahan

Illuminating Engineering Laboratory, General Electric Company

But little advance has been made toward the better lighting of piers and docks. This condition is inexcusable because suitable lamp units have been available and their installation in progressive industrial plants has demonstrated the material benefits resulting from adequate illumination. The following article describes the several types of modern lighting units that will economically furnish the intensity and distribution of light necessary for the rapid and efficient performance of work on piers and docks, in warehouses, and in large outdoor storage areas.—Editor.

H. E. Mahan

THE success of the American merchant marine depends largely upon the ability to construct, operate, load, and unload vessels with efficiency and dispatch. Statistics indicate that one of the greatest handicaps to the efficient execution of this program is the delay in loading and unloading.

These operations are carried on during the night as well as the day, and we may therefore conclude that proper artificial illumination may contribute in no small degree to expediting the work.

An investigation of lighting conditions along the water front of one of our largest ports disclosed appalling conditions regarding the inadequacy of the artificial illumination.* Obsolete equipment was the rule

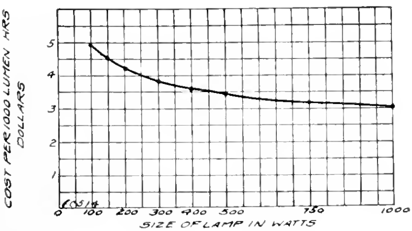

Fig. 1. Cost of Producing Light with Mazda C Lamps

rather than the exception. The lighting units were improperly installed and equipped, with the result that the piers were in general so dark as to make convenient progress around the floors impossible, time was lost in endeavoring to read and interpret labeling, material could not be handled efficiently, policing was difficult and the accident hazard very great. The continued congestion, especially in New York, during the war months

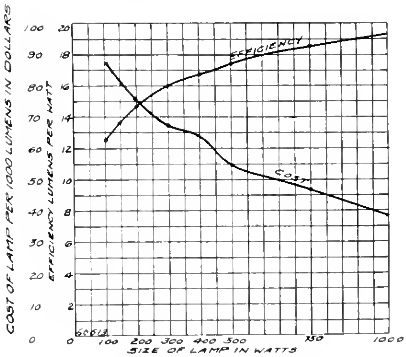

Fig. 2. Cost and Efficiency Curves on Mazda C Lamps

made working conditions about the docks less safe than before.

The increased cost of installing and maintaining a system of good lighting as compared with a poor system is so slight that it is poor economy to adopt the latter with all its short-comings; furthermore, it should be borne in mind that the cost of adequate and correct lighting is a very small item compared with the total operating expenses. In considering the cost of producing light it is interesting to note Figs. 1 and 2. It will be seen from these curves that the efficiency of lamps increases with the size of the lamp, while the cost of the lamp per lumen capacity decreases. As the cost of light is made up of the cost of power plus the cost of lamps, it follows that light may be produced at less cost the larger the lamp employed. The cost of wiring and installing is also corre-

* "Light as an Aid to Transportation of Material," by A. L. Powell and R. E. Harrington, Transactions I.E.S., February, 1919.

Fig. 3. Form 1 Novalux Pendent Unit, Canopy Type, Equipped with 10½-in. Refractor and No. 85 Globe Reflector

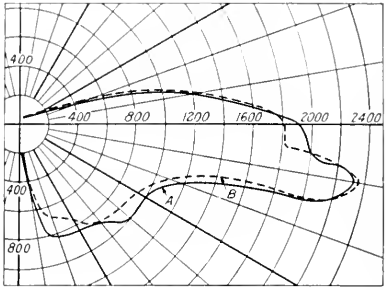

Fig. 4. Distribution of Candle-power of the Form 1 Novalux Pendent Unit Equipped as Shown by Fig. 3.

Fig. 5. Installation of Novalux Units Equipped with Reflector Globes at New York Dock of France and Canada Steamship Corporation

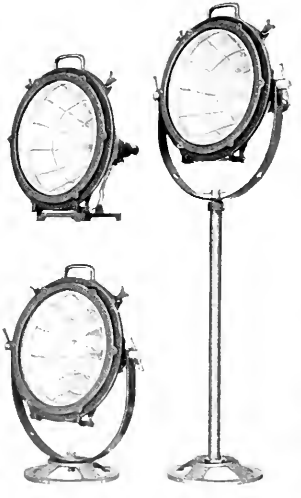

Fig. 7. The Form L-3 Floodlighting Projector Showing Several Methods of Mounting

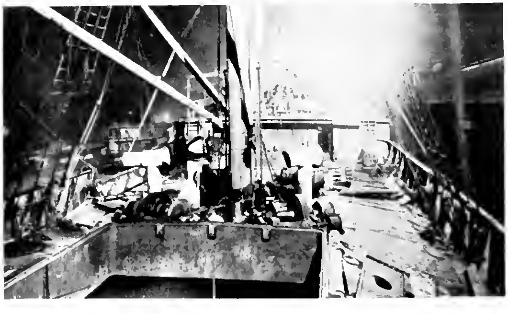

Fig. 6. Ship Illuminated at Dock of France and Canada Steamship Corporation. See Fig. 5.

spondingly less for fewer outlets using large units than for a relatively large number of outlets with smaller lamps. These considerations, however, should be weighted with the fact that the greater number of lamps provides the most desirable distribution of light and less chance for shadows which, of course, is very important in lighting storage spaces such as pier sheds where material is stacked indiscriminately over the entire floor space. The height of suspension is also a factor entering into this problem.

Fig. 8. Form 1 Novalux Fixture, Straight Multiple Type with Short Casing, 10 1/2-in. Band Refractor and No. 14 Globe

A satisfactory system of illumination for piers and docks should possess the following characteristics:

(1) Good distribution and diffusion in order that a fairly uniform illumination may be depended upon regardless of the arrangement of material.

(2) Sufficient intensity of illumination in both the horizontal and vertical planes to enable one easily to read labels and markings.

(3) Ample illumination at the proper points to facilitate the loading and unloading, docking, etc., of ships.

(4) The foregoing requirements to obtain without conditions of glare or other disturbing factors detrimental to ease of vision, safety of workmen, etc.

The type of unit selected for any particular set of conditions will depend largely on the

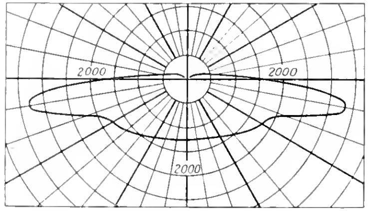

Fig. 9. Distribution of Candle-power of the Form 1 Novalux Pendent Unit Equipped as Shown by Fig. 8

structural features and local requirements. A review of available equipment, together with their characteristics and methods of installing, will perhaps give a general idea of the problem and its solution.

Fig. 3 illustrates a lighting unit with a half silvered globe and Fig. 4 indicates the dis-

Fig. 10. Novalux Units and Floodlighting Projectors Mounted on 50-ft. Pole. Hog Island Shipyard, Philadelphia, Pa.

tribution of light from such an equipment. It will be noted that the distribution is asymmetrical, which makes the unit particulalry well adapted to provide light for loading, unloading, docking, etc., all of which require that the illumination be furnished alongside

Fig. 11. Shipways Illuminated by Floodlighting Projectors and Novalux Units Hog Island Shipyard, Philadelphia Pa.

Fig. 12. Freight Yard Illuminated by Novalux Units. Hog Island Shipyard, Philadelphia, Pa.

the piers. A view of these units installed is shown in Fig. 5. A night view of the same installation is shown in Fig. 6.

It is necessary, at times, when working in the holds of vessels, to supplement the general lighting with local lights. A type of unit suited for this service is the floodlighting projector shown in Fig. 7. The reflector in this unit is built up of glass segments arranged in three zones and delivers a wide distribution of light. The distribution may be further modified by substituting other types of doors in place of the standard clear glass type. A stippled glass door delivers a diffuse distribution and a factory ribbed door provides an asymmetrical distribution which makes it possible to spread the light in one direction and shorten it in the other.

Floodlighting equipment is available in a number of different types of distribution and finds application in many ways for such outdoor work as is carried on in construction, railroad yards, docking ships, loading and unloading freight, etc. Care should be exercised, however, in using equipment of this kind to avoid excessive glare and dark shadows.

Fig. 13. Ivanhoe Metal Reflector Bedd-200 RLM Standard Dome. Clear, Bowl Frost and Bowl Enamel Lamp

The lighting of large areas, such as outdoor storage yards, construction work, ship-building, repair yards, etc., requires large units with a distribution peculiar to the needs of this service. Such a unit is shown in Fig. 8 and consists of the casing, $10\frac{1}{2}$-inch band refractor, and clear globe. This unit accommodates the larger sizes of Mazda lamps and delivers the distribution of light shown in Fig. 9. It will be noted that the distribution of light is such as to provide the maximum candlepower about 10 deg. below the horizontal,

Fig. 14. Form 6 Novalux Fixture Equipped with No. 87 Globe and 20-in. Porcelain Enameled Reflector

so that when suspended at a height of from 30 to 60 feet it illuminates a wide area to a fairly uniform intensity. Groups of four of these units were used for general lighting throughout the grounds at the Hog Island Shipyard, Philadelphia, Pa. Fig. 10 illustrates a typical installation at this yard. In this same illustration is shown the application of floodlighting projectors for supplementing the general illumination at points requiring additional intensity. A night view of the ship ways illuminated by this type of equipment is illustrated in Fig. 11; and Fig. 12 is a night view of a freight yard illuminated by units of the same type.

The lighting of pier sheds in its requirements is analogous to the lighting of a warehouse. Industrial lighting units such as are illustrated in Figs. 13 and 14 are particularly well adapted for this purpose, being rugged mechanically and efficient in the distribution of light. The New York State Industrial Code recommends 0.5 to 1.0 foot-candle for storage spaces. Inasmuch as the requirements on a pier are more exacting than those for dead storage, an intensity of at least 2 foot-candles is desirable. This requires equipment aggregating 0.25 to 0.50 watts per square foot of floor space, depending upon local conditions. Proper painting of the walls and ceilings will serve to increase the distribution and intensity of both the daylight and artificial light. In selecting a paint, a good flat white should be chosen

Fig. 15 Multiple Automatic Cutout with special Binding Posts

which possesses the quality of permanence. There are a number of such paints on the market which have been developed in accordance with the requirements of good lighting.

A typical layout for a pier shed is shown in Fig. 16, from which it will be noted that a calculated illumination of approximately 2.6 foot-candles has been provided. The outlets are staggered so as to minimize the possibility of stacks of material cutting off entirely all sources of illumination from any area.

There are several important factors to consider in connection with the maintenance of a lighting system if it is to continue to deliver its initial output. In the first place, a loss of as much as 50 per cent is sometimes found from the accumulation of dirt on the reflectors and lamps. This, of course, can be reduced to a negligible amount by periodic cleaning and the results warrant the expense of such attention. In order to facilitate the cleaning of lamps which are mounted at such heights or locations as to make handling inconvenient from a ladder, it is advisable to employ the automatic cutout, a type of which is illustrated in Fig. 15. This enables the lamp to be lowered to the ground for cleaning or re-lamping.

The next important consideration is to have lamps of correct voltage. A lamp which is operating below voltage has its light reduced approximately 3.5 per cent for each volt reduction. The lamp manufacturers advise that the labeled voltage on a lamp be the same or at least no higher than the actual average voltage at the lamp socket in which the lamp is used.

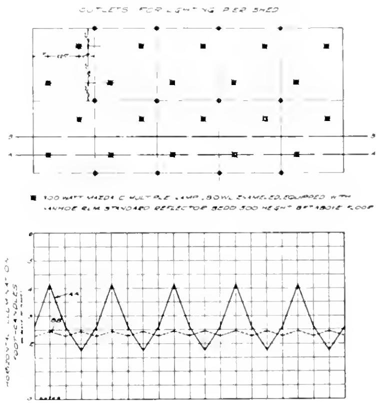

Fig. 16. Arrangement of Outlets for Lighting Pier Shed

A start in the direction of adequate lighting for our water fronts was made by our Government during the period of the war and no doubt an appreciation of the advantages accruing therefrom will spread throughout the shipping world.

A Painting of the Battleship *New Mexico* Presented to the U. S. Navy Department by the General Electric Company

The original of our frontispiece to this issue, a canvas of the first electrically driven battleship U.S.S. *New Mexico*, was presented to Secretary Josephus Daniels for the Navy Department by E. W. Rice, Jr., President of the General Electric Company, on February 28, 1921.

This painting, the work of Walter L. Greene, artist for the General Electric Company, is a truly magnificent specimen of marine art, portraying with wonderful fidelity the atmosphere of sea and ship, and was pronounced by Rear-Admiral W. S. Benson to be the best naval painting that he had ever seen. The artist has displayed real genius in conveying an impression of speed and might that is wonderfully expressive of the progress represented by the development of electric ship propulsion. The three flags flying from the signal halyards announce what the bow wave confirms, "full speed ahead," while the guns and turrets, which are the most striking features of a battleship to the average person, are masterfully portrayed. The painting is a visual expression of the art and romance that is a part of the scientific and industrial world of today.

Mr. Rice's address in presenting the painting to the Navy Department and Secretary Daniels' address of acceptance follow:

"*Mr. Secretary of the Navy and Gentlemen:*

"The Navy Department of our Government has contributed more important advances in engineering than is perhaps generally appreciated by many well-informed people.

"I will not even attempt to mention the numerous developments which the Navy has either stimulated or originated, but do wish to briefly outline one of the big forward steps of recent years in which the Navy has played a great and indispensable part, namely, the development of the steam turbine electric drive for ships.

"Time will not permit us to trace the interesting evolution of the application of mechanical power to ships. I will merely recall to your minds that sails and oars were the only devices in use for countless ages, even down to the time of our grandfathers, less than one hundred years ago.

"The first advance then took place in the substitution of steam through the reciprocating engine for the blowing of wind upon the sails. This great event occurred as stated about a century ago, and the steam engine was our only source of mechanical power up to the last quarter of the 19th century when the steam turbine made its appearance.

"The application of the steam turbine to the driving of ships may be considered as an event only exceeded in importance by the original substitution of steam for sail power in such service.

"The full benefits of the steam turbine could not be realized because the turbine is inherently a very high speed machine, while the propeller is best adapted to and is most efficient at relatively slow speeds. The direct connection of the turbine to the propeller shaft was the simplest and most rugged method and was naturally the plan first adopted. Unfortunately this method of application demanded compromises in the design of both turbine and propeller which were only obtained by relatively large sacrifices of efficiency in both.

"Therefore the constant search for improvement soon led to the introduction of mechanical reducing gear between the high speed turbine and the low speed propeller. While the improved efficiency which resulted marked another forward step, it was obtained at the expense of mechanical complications. Furthermore, it must not be forgotten that in both the direct drive and in the geared drive, the power available in reversing the direction of motion was greatly limited.

"That electricity could be used as a substitute for gears was perhaps obvious, but it was not obvious that it would be practical or economical. In fact, at first sight it would seem both foolish and wasteful to resort to the double transformation of power, involved in first generating mechanical power from steam, converting this into electricity and then to reconvert the electricity back again into the mechanical power needed to drive the propellers.

"That the electric drive could by any possibility prove to be the best and more generally efficient, seems a paradox. What is the cause of the undoubted success of this paradoxical device? It is due, largely, we believe, to the fact that in the electric drive an open air space is substituted for the teeth of the mechanical gear, and yet although we remove the teeth we are able to transmit tremendous power without any mechanical contact. There is in fact no mechanical connection between the fixed and moving parts of the electric motors which may be regarded as the new electric gear, one which by its very nature, prevents the transmission of destructive shock or strain.

"The electrical method substitutes an indestructible infinitely elastic air space for the teeth of the mechanical gear and obviously the air space cannot be bent, or broken, requires no lubrication and contains nothing to rub, or get out of order. The electric drive also permits of a complete and instantaneous reversal of the direction of motion and thus enables the ship to move backward, as well as forward, under full power and adds enormously to its ability to maneuver definitely and quickly.

"The electric gear has the additional advantage that it can be arranged to give great variation in the speed ratio or leverage between the turbine and propellers which is a feature of the greatest practical value. It permits operation of the ship at different speeds with full efficiency, thus realizing a large saving in fuel, a feature of untold importance in naval vessels, especially in wartime, as it greatly increases the cruising radius obtainable before renewal of fuel.

"This briefly indicates what seems to be some of the technical reasons which justify the adoption of the electric drive.

"The first seagoing ship equipped with turbine electric drive was the U.S. collier *Jupiter* of 20,000 tons rating. She was built under the direction of our Navy Department. The *Jupiter* was one of several sister ships, but was the only one equipped with the electric drive.

"Comparative tests of the *Jupiter* clearly indicated the superiority of the electric drive and thus gave courage to those interested in the equipment of other large ships and finally led to the designing and building of the U.S. battleship *New Mexico* launched in 1917, the first battleship to be equipped with electric drive. The high overall efficiency and other advantages of its propelling machinery as compared with the type of equipment in use on previous battleships has been fully demonstrated under all the conditions encountered in actual sea service.

"As a result, I understand that our Navy Department has adopted this type of drive for all capital ships which have since been designed or contracted for.

"It may assist us in forming a proper appreciation of the magnitude of the power plant required for the operation of the battleship *New Mexico* to remember that its power plant is of sufficient size to furnish all the electricity used for light and power as well as for the operation of the street cars in a modern city of 200,000 people.

"This new and apparently perfect method of propelling ships is of prime importance and value to our country, not only because it has resulted in placing our Naval vessels and equipment in a highly satisfactory position of world leadership, but because it has also pointed the way to the use of electricity in the propulsion of our merchant marine.

"It must be a great satisfaction to every Navy man to remember that the modern steam turbine electric drive for ships resulted largely from the work of a graduate of our great Naval Academy at Annapolis, Mr. W. L. R. Emmet, who with a thorough understanding of the principles involved, attacked the problem and with patience and perseverance continued to overcome all obstacles until success was won.

"It is also a subject for congratulation that his efforts were only made successful as a result of the splendid co-operation and support which he received from the Navy Department presided over by its Secretary, Mr. Daniels.

"Such important undertakings can only be brought to a successful conclusion by the united assistance of those who are best informed both as to the operation of the apparatus and its design and manufacture.

"As the *New Mexico* was the first battleship in the world to be driven by steam turbine electric drive, it seemed fitting, as a part of the record of the achievement to have a painting made of this ship. The commission was executed by the artist, Walter L. Greene, and I take great pleasure in presenting it in the name of the General Electric Company to the Navy Department of our Government through our Secretary, the Honorable Josephus Daniels, during whose administration the ship was designed, built and put into commission."

SECRETARY DANIELS:

"*Mr. Rice and Gentlemen:*

"It is a privilege to speak for this great Department of the Government which, you have truly said, has inaugurated many new things that have strengthened our Navy and which have blazed the way for a greater merchant marine. I wish to thank you in the name of the Navy for this beautiful picture of the *New Mexico*, which is the last word in naval efficiency.

"I remember very well, shortly after I became Secretary of the Navy, in discussing with Admiral Winterhalter and Admiral Griffin the plans for the construction of our new and greatest ship; the suggestion was under consideration whether the success of the electric drive on the *Jupiter* justified its adoption in the new dreadnaughts. There was much difference of opinion in the Navy and outside the Navy among engineers of ability as to the wisdom of what was truly a revolutionary departure in the propulsion of battleships. During the discussion I shall never forget spending a whole evening with Bill Emmet—we call him 'Bill' in the Navy because he graduated from the Naval Academy—(I guess you call him by some high title in the General Electric Company). He is ordinarily a phlegmatic man, quiet and reserved about most matters, but I can never forget his enthusiasm and his wonderful spirit of faith as he discussed it and undertook to convince me that he and Griffin and Dyson and Evans and others in the Navy, and Winterhalter, were right, and the plan of electric propulsion for battleships should be adopted by the Navy.

"After all, the world is moved by enthusiasm based upon knowledge. It was the enthusiasm of Emmet and our own able engineers that interested me first in the electric drive. I am by nature somewhat of a revolutionist. All the changes in the Navy from sailing to the electric drive have come by men who know that the best is yet to be.

"You may remember, when the decision was made and it was determined to put the electric drive in the *New Mexico* and then determined to put it in all our great ships, there was in and out of the Navy strong protest. It came to me by letters and by telegrams and by personal interviews. Not a few predicted that if I approved this method of propulsion I would ruin the Navy. My reply was: 'Well, I have ruined the Navy so many times one more time will not make any difference!' And so the decision was made. Its opponents carried the fight to Congress. A number of engineers went before the Congress to point out that a great battleship run by electric drive was bound to prove an expensive failure and said, 'Let some other nation try it first.' Well, we had a long debate and discussion and the Congress finally decided wisely (I say it with modesty) I think, to let the Secretary of the Navy settle it. The *Jupiter* had just come through the Canal. It had weathered the greatest storm in the Atlantic in twenty years and had come through in fine shape. I went to New York and spent a day on it. I liked the looks of it and when I found that the captain and engineers and officers were enthusiastic about it, I came back and found our experts strengthened in the belief it was the modern method of propulsion. I was very glad to have the honor and privilege to sign the order which in the *New Mexico* put America in the lead in electric propulsion, as we were in the flying machine and the submarine and other improvements in ships of the sea and air. When abroad two years ago I found able naval constructors and engineers who congratulated the American Navy in being the first to take this forward step which will eventually be adopted by all countries.

"It will interest you to know of one of the most distinguished Admirals in our Navy, a man who was in command of the battleships in the North Sea, an old-fashioned sailorman of great ability and brains—none better in the world. In the main he holds to the old ways of sea-going. I refer, of course, to Admiral Hugh Rodman. At first he doubted the wisdom of this new innovation. I spent ten days on the *New Mexico* last summer with him cruising from Los Angeles up to Seattle, and Admiral Rodman said: 'I want you to come with me all over the flagship, particularly to see how the electric drive works. It ought to be adopted throughout the Navy. Thirty per cent is saved in money and in cleanliness and in every element that makes an efficient ship. I was opposed to it at first but I am willing to confess I was wrong, and the engineers and experts in the Department and out of the Department were right.' That shows he is the kind of big man who will change an opinion when convinced.

"I thank you for the Department and for the country for this gift which will adorn the walls of the Department, and I thank you for the part, and the large part, the General Electric Company has played in this improvement—an improvement along the line of other things which your great company has done in progress and development."

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Balancing

Martin's Rotor Balancing Machine.
Elec. Rev. (Lond.), Jan. 28, 1921; v. 88, pp. 101-102.
(Illustrated description of the apparatus and examples of results obtained by its use.)

Converters, Synchronous

Voltage Regulating Systems of Synchronous Converters. Hague, F. T.
Elec. Jour., Feb., 1921; v. 18, pp. 52-56.

Current-collecting Devices

Electric Railway Contact Systems. Dawson, Sir Philip.
I. E. E. Jour., Sept., 1920; v. 58, pp. 838-857.
(With several illustrations showing British practice.)

Electric Current Rectifiers

Converting of Single Phase and Polyphase Current to Direct Current by Means of the Mercury Vapor Rectifier. (In German.)
Trua, Jan. 15, 1921; v. 2, pp. 133-139.
(Illustrated review of the general principles and of modern installations, with special reference to the large size A. E. G. apparatus.)

Electric Drive—Power Plant Auxiliaries

Dual Drive Units. Forde, Ivan Stewart.
Elec. Jour., Feb., 1921; v. 18, pp. 48-50.
(Explanation of the advantages of both motor and steam turbine drive to ensure continuity of operation of any auxiliary device.)

Electric Drive—Textile Mills

Continental Practice in the Electrical Driving of Textile Factories. Fox, W. Dundas.
Elec'n (Lond.), Feb. 4, 1921; v. 86, pp. 165-168.
(On European methods. Includes graphs showing operating statistics.)

Electric Furnaces

Electric Annealing and Heat Treating Furnaces. Mills, George P.
Assoc. Ir. & St. Elec. Engrs., Feb., 1921; v. 3, pp. 1-20.
(On the general principles of electric heat treating and annealing.)

Relative Economy of Oil, Gas, Coal and Electric Heated Furnaces. Moulton, Seth A. and Lyman, W. H.
Am. Soc. St. Treat. Trans., Jan., 1921; v. 1, pp 249-270.
(Statistical paper.)

Electric Locomotives

Economic and Technical Points in the Construction of Recent Large-Size Electric Locomotives. Laternser, Alb. (In German.)
Schweiz. Bau., Jan. 29, 1921; v. 77, pp. 49-51.
(Critical review of the recent locomotives built by General Electric, Westinghouse and by some European firms.

New Three-Phase Locomotives for the Italian State Railways.
Rwy. Gaz., Jan. 28, 1921; v. 34, pp. 103-105.
(Illustrated description of Brown Boveri locomotives.

Electric Power

Policies for Future Power Development. Jackson, Col. John Price.
Mech. Engng., Feb., 1921; v. 43, pp. 102-107, 110.
(A general paper on the demand for central station power and how it may best be met.)

What Superpower Means. Flood, Jr., Henry.
Power, Feb. 15, 1921; v. 53, pp. 267-270.
(An explanation of the objects and proposed methods of the Atlantic seaboard superpower scheme.)

Electric Precipitation

Cottrell System of Dust and Fume Precipitation.
Engng. (Lond.), Jan. 28, 1921; v. 111, pp. 94-97.
(Illustrated description of the process as used by the Royal Navy Cordite Factory, England, for suppressing sulphuric acid fumes.)

Electrical Machinery—Temperature

Temperature Limits of Large Alternators. Juhlin, G. A.
Elec. Rev. (Lond.), Feb. 4, 1921; v. 88, pp. 154-156.
(Abstract of technical paper read before I. E. E. Also in *Elec'n.* (Lond.), Jan. 28, 1921; pp. 126-129. Serial.)

Temperature Rise in Headlight Generators.
Rwy. Elec. Engr., Feb., 1921; v. 12, pp. 80-83.
(Shows results of tests made on C. C. C. & St. L. Railroad.)

Electrolysis

Protection of Cables Against Electrolysis.
Rwy. Sig. Engr., Jan., 1921; v. 14, pp. 32-36.
(Methods of detection and prevention of electrolysis in telegraph and telephone cables.)

Inductive Interference

Minimizing Inductive Interference. Wray, J. G. and Hill, Cyrus G.
Tel. Engr., Feb., 1921; v. 24, pp. 21-27.
(Treated from the standpoint of the telephone engineer.

Power Interference on Telephone Circuits. Dall. E. M.
S. Af. I. E. E. Trans., Dec., 1920; v. 11, pp. 231-241.
(Gives results of tests carried on in Johannesburg, South Africa. Includes many diagrams.)

Load Factor

Effect of Load Factor on Steam-Station Costs. Junkersfeld, Peter.
Mech. Engng., Feb., 1921; v. 43, pp. 108-110.

Load Factor: Its Definition and Use. Kensit, H. E. M
Can. Engr., Jan. 20, 1921; v. 40, pp. 149-151.
(A compilation of definitions by several recognized authorities.)

Magnets

Permanent Magnets in Theory and Practice. Evershed, S.
I. E. E. Jour., Sept., 1920; v. 58, pp. 780-837.
(With its accompanying discussion forms a lengthy paper on the subject.)

Protective Apparatus

Protection Against Excess Voltage and Current According to Recent German Installations. Massing, H. (In French.)
Revue Gén. de l'Elec., Jan. 22, 1921; v. 9, pp. 99-104.
(General account of methods used in Germany.)

Railroads—Electrification

Application of the Electric Locomotive to Main-Line Traction on Railways. O'Brien, Lieut.-Col. H. E.
I. E. E. Jour., Sept., 1920; v. 58, pp. 858-869.
(Includes many graphs and tables of data as applying in British practice.)

Rotation

Calculation of Torsional Vibrations and Critical Speed of Shafts. Sass, Fr. (In German.)
Zeit. des Ver. Deut. Ing., Jan. 15, 1921; v. 65, pp. 67-69.
(With special reference to high speed oil engines and steam turbines.)

Critical Speed of a Turbine Spindle. Gardner, Richard.
Engng. (Lond.), Jan. 28, 1921; v. 111, pp. 99-100.
(Mathematical.)

Steam Plants

Steam Accumulator System. (In Norwegian.)
Tekn. Uke., Jan. 21, 1921; v. 68, pp. 27-32.
(A Swedish system for the storing of exhaust steam for use in times of peak load or for other purposes.)

Switches and Switchgear

Line and Generator Switching at Niagara Falls. Hayes, Stephen Q.
Elec. Rev. (Chgo.), Feb. 5, 1921; v. 78, pp. 203 207.
(Illustrated description of equipment at the Niagara Falls Power Company.)

Voltage Regulation

Voltage Regulating Systems of Synchronous Converters. Hague, F. T.
Elec. Jour., Feb., 1921; v. 18, pp. 52-56.

Waste Heat

Waste Heat Utilization. McDermott, G. R. and Wilcox, F. H.
W. Soc. Engrs. Jour., Feb., 1921; v. 26, pp. 60-76.
(Technical paper on utilization of waste heat from metallurgical processes.)

Water Power

Ontario Power Commission. Its Origin and Development. Biggar, E. B.
Jour. Pol. Econ., Jan., 1921; v. 29, pp. 29-56.

Water-Power Applications, 13,469,181 Hp.
Elec. Wld., Feb. 12, 1921; v. 77, pp. 369-370.
(Data on applications, up to January 29th, for water-power permits under the Federal Water Power Act.)

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Abrasives

Jacobs, Fred B.
Abrasives and Abrasive Wheels: Their Nature, Manufacture and Use.
338 pp., 1919, N. Y., The Norman W. Henley Publishing Company.

Construction Materials

Moore, Herbert T.
Text-Book of the Materials of Engineering. Ed. 2.
315 pp., 1920, N. Y., McGraw-Hill Book Co.

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Tucker, James Irwin.
Contracts in Engineering. Ed. 2.
331 pp., 1920, N. Y., McGraw-Hill Book Co.

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190 pp., 1920, N. Y., John Wiley & Sons, Inc.

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Curtis, Thomas S.
High Frequency Apparatus; Design, Construction and Practical Application, Ed. 2.
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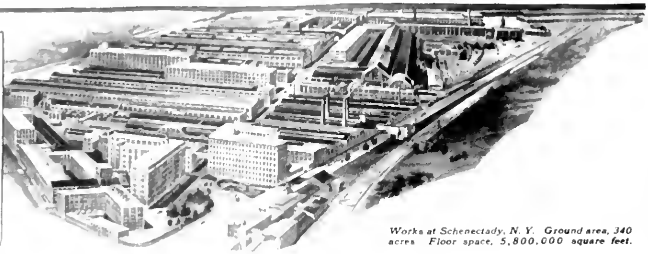

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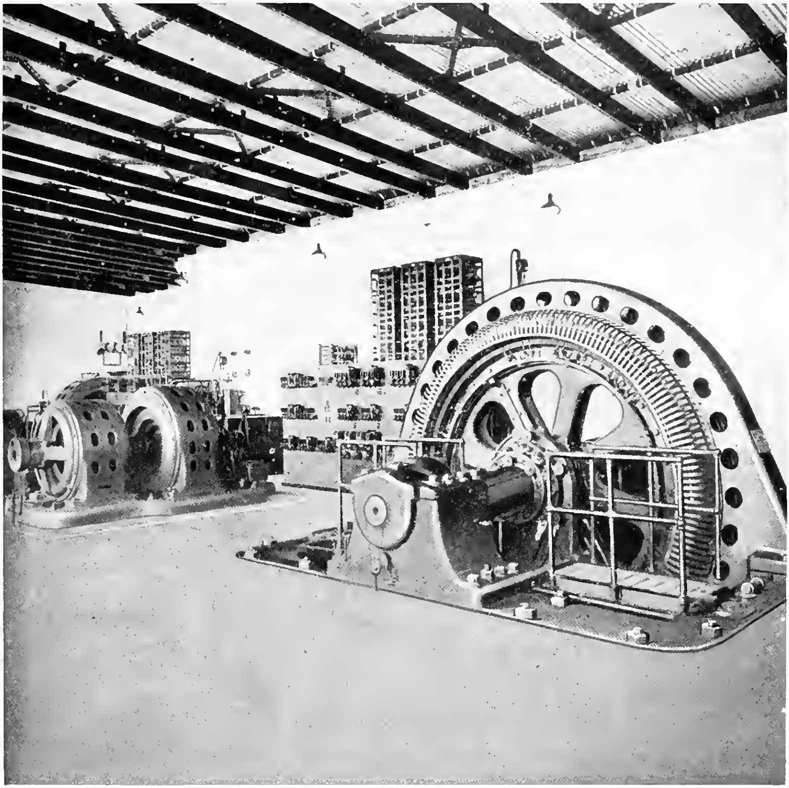

STEEL MILL INDUCTION MOTOR INSTALLATION WITH SCHERBIUS SYSTEM OF SPEED CONTROL.
REGULATING SET ON LEFT; MAIN MOTOR ON RIGHT

(See article, page 422)

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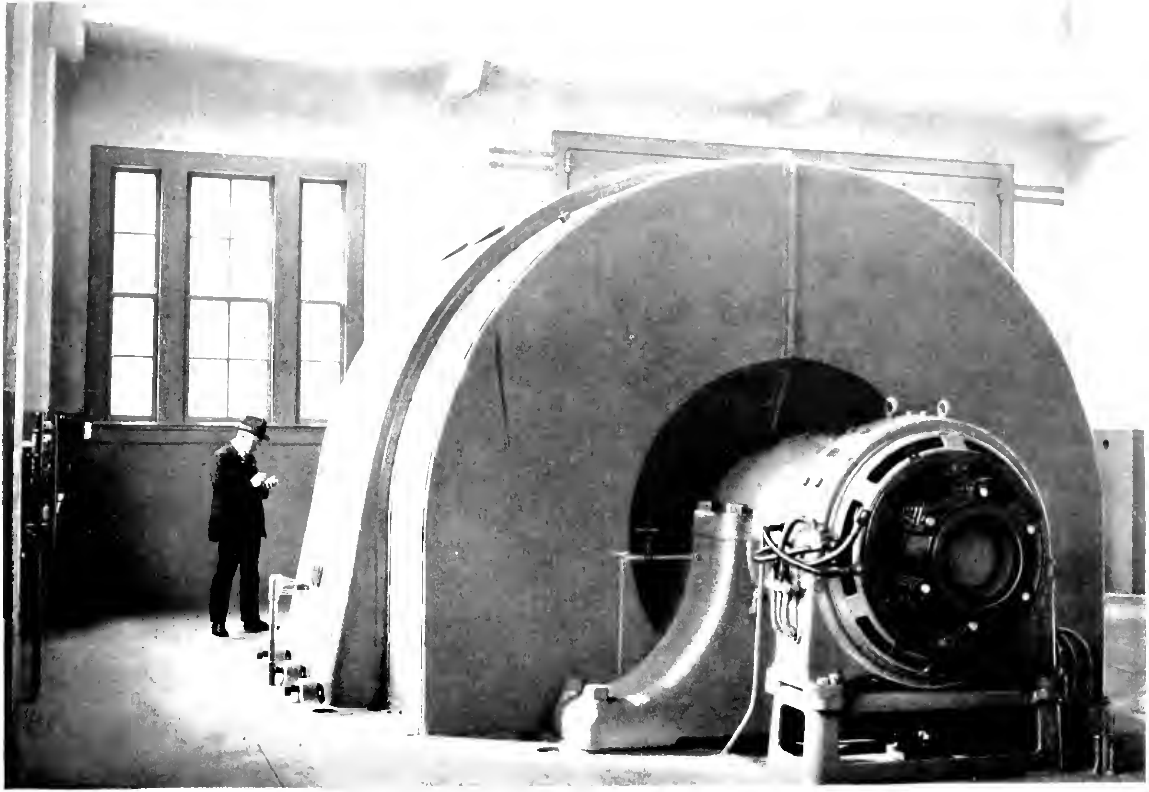


30,000 kv-a., 6600 volt, 3 phase, 50 cycle Synchronous Condenser Located in the Eagle Rock Substation of the Southern California Edison Company. Two articles relative to the future operation of the transmission lines of this company at 220,000 volts appear on pages 397 and 399 of this issue

GENERAL ELECTRIC REVIEW

THE CIRCULAR-COIL HIGH-VOLTAGE TRANSFORMER

Power transmission at 220,000 volts is scheduled to become an accomplished fact in the near future. Confidence in the attainment of this transmission voltage has long been inspired by the successful operation of 150,000-volt lines, but the actual construction of such an installation has been delayed by the diverting activities of war.

Because the constant trend toward higher transmission potentials has inclined us to speak offhand of the pressures as so many kilovolts, and because the present abrupt jump brings us up to the value which has been predicted as the standard for future long-distance super-power systems, it might be well to pause a moment and in terms other than voltage consider the effectiveness of power transmission at this potential. Under such a degree of pressure, the concentration of energy is so great that 100 horse power could be transmitted by the filament in an ordinary 40-watt incandescent lamp without heating this minute conductor above its normal operating temperature or shortening its rated life.

An explanation of the conditions which have led the Southern California Edison Company to take active steps toward employing 220,000 volts is set forth in the article by Mr. Barre in this issue and the circular-coil type transformers that will be used are described by Mr. Jones. While it is only natural that the attention given to those things that are newest and biggest should with pride be directed to these transformers, which are being built for the highest operating voltage in the world, the really significant fact is that their manufacturer has for years been building transformers of the same general type and therefore in the construction of these super-voltage units was not obliged to resort to radical changes in design.

The mere use of the circular coil, even though it be a fundamental requisite of the best practice, is not in itself a proof of superior results. Such results are, no doubt, possible only with that extended experience which enables the manufacturer to gauge correctly all of the factors entering into the design of the apparatus and to appreciate fully the limitations as well as the value of his methods. Fortunately, in this instance, the manufacturer has had just that experience, and there is, therefore, that assurance of success which is to be expected of a construction that has passed through its developmental stage and has established an enviable record in service. The importance of this achievement and its significance in pointing the way for the best power transformer practice are of general interest to all power transformer users. Past experience has shown beyond question that the circular-coil design is invaluable in the construction of superior transformers for any class of service; and the years already spent in the development, standardization, and quantity production of units of this type have enabled the manufacturer to reduce his costs to a point well within the competitive range of less expensive and less desirable constructions.

While the opinion has recently been stated editorially that the difference between the collective merits of the circular-coil and the rectangular-coil type of construction will probably not materially affect the quantity production of either type, convincing evidence to the contrary is at hand through information that other manufacturers have already begun to use the circular-coil design in the larger and more important units.

A matter of further interest is the oil conservator tank which apparently has also "come to stay" in the transformer field. Service records already show that this device solves the moisture problem completely and this alone would make it indispensable, particularly for outdoor installations. Its additional advantages, in preventing oil decomposition and in protecting the usual transformer insulations, are extremely important from the economic as well as the operating viewpoint and they bid fair to add a large percentage to the useful life of the apparatus.

MAINTAINING THE CONDITION OF STEAM TURBINE OIL

A [illegible] in engineering education is that lubrication is of first importance in the operation of any piece of machinery. Any layman who has had the task of keeping an automobile in repair appreciates this truth. Length of service is simply a matter of wear, and wear is a matter of lubrication.

In steam turbines the high temperatures produced by superheated steam and the high journal speeds create difficulties in bearing lubrication that are peculiar to this type of engine. Fortunately, the bearing pressures per square inch are relatively low as a rule; but these pressures are increasing with the increase in size of units, necessitating a more rapid circulation of the oil and the need for greater diligence in maintaining its lubricating properties at the maximum.

In the early days of steam turbine development much trouble was experienced with bearings owing largely to the fact that the only lubricating oils that were available were developed for other purposes and were unsuitable for steam turbine use. Diligent research, however, has remedied this deficiency and today troubles in almost all cases are due to the wrong use of oil rather than the use of wrong oil. Abuse and neglect of the best oil will kill it in a surprisingly short time, while extensive tests have pretty thoroughly proved that good oil, if kept free from foreign substances, does not lose its lubricating properties after years of continuous use.

Turbines in modern power plants are in many instances required to run for long continuous periods, a condition which does not permit of drawing off the oil at stated intervals for filtration and purification. A satisfactory system of oil treatment therefore requires that some means be employed of purifying the oil in the course of its circulation through the oiling system. If the entrapped water, air and small particles of solid matter can be continuously removed from the oil no emulsification will occur, and without emulsification slugging is impossible.

This highly important matter of oil purification is ably discussed in this issue by C. H. Bromley. The general subject of lubrication and lubricating oils has only been briefly considered in the GENERAL ELECTRIC REVIEW from time to time, but the editors are now able to promise a series of articles on this interesting phase of engineering.

THE MODIFIED SCHERBIUS SYSTEM

The simple construction and splendid reliability of the induction motor were powerful incentives to the steel mill owner to adapt his mill to induction motor speed characteristics. This change would do away with the more delicate and less efficient direct-current equipments that for a long time were necessary for mills requiring adjustable speed over a considerable range. Of course, the single speed induction motor was immediately applicable to mills rolling a single product requiring only one speed, but where a variety of sections were rolled in the same mill, or where the product was in several mills at one time, it was of advantage and often absolutely necessary to have adjustable speed. Many schemes have been developed for altering the speed of induction motors for steel mill service, but the outstanding methods are the modified Scherbius system and the Kraemer system, both of which are described and compared by K. A. Pauly in this issue.

Where the speed of the induction motor is controlled by resistance a series characteristic obtains, that is, the speed is proportional to the load and the speed range depends upon the amount of resistance and the load. With resistance control the overall efficiency is very low when running at reduced speeds. With the modified Scherbius system the desirable induction motor characteristics are preserved, that is, the speed of the motor may be controlled at no load, and when the load is applied there is a change in speed from no load to full load which is only slightly greater than the slip of a corresponding simple induction motor; conversely when the load goes off the speed remains practically constant, corresponding to the setting of the control, and does not increase to synchronism as with resistance control. The overall efficiency of the Scherbius system is high, and in addition a means exists for correcting the power factor of the induction motor. An equally important feature is that the high pull-out torque of the induction motor is preserved at all speeds.

The double range Scherbius system makes it possible to place the synchronous speed of the induction motor approximately in the center of the speed range, thus permitting of absolutely dependable operation over a considerable range both above and below synchronism. The ability to run at intermediate speeds is an advantage because a large variety of sections can be rolled at these speeds without the use of the auxiliaries, and therefore with an increase in overall efficiency and a reduction in maintenance.

Present Status of Conversion of Big Creek Line of Southern California Edison Company from 150,000 to 220,000 Volts

By H. A. Barre

Executive Engineer, Southern California Edison Co.

Faced by the necessity of increasing the carrying capacity of its transmission line either by building additional circuits or by raising the voltage of the existing line, the Southern California Edison Company has selected the latter alternative as being the more economical. The preparations for the transition to 220,000 volts are outlined in the following article. The auto-transformers referred to, for raising the line voltage from 150,000 to 220,000 volts, should not be confused with those described by Mr. Clinton Jones elsewhere in this issue. The latter are to be used for tying in a new generating station through a single transformation from 11,000 to 220,000 volts.—Editor.

For several years past the Southern California Edison Company has been engaged in studying the power resources of the San Joaquin River and preparing a program for their development as the demand for power grows. The progress of these studies developed the fact that there were between 700,000 and 800,000 kw. available, the larger part of which must be transmitted to Los Angeles, a distance of 240 miles. Since the capacity of the two 150,000-volt circuits now operating over that distance is 55,000 kw. each, it was quickly apparent that the possibilities of higher voltages must be studied to reduce the number of circuits and to obtain a correspondingly reduced cost per kilowatt transmitted.

The rapid growth of the load indicates that additional plants must be developed and placed in operation by 1923, at which time additional capacity will be needed.

Raising the voltage of the present Big Creek 150,000-volt lines to 220,000 volts promises to be the quickest and cheapest method of obtaining the increased capacity. On account of the fact that in case anything develops to make this plan impracticable, additional circuits must be built in time to coincide with the completion of the power plants, the Company has decided to proceed as actively as possible with the necessary development work on the transmission line at the present time. The problem of the Edison Company is, therefore, not the general one of how to build a 220,000-volt transmission system, but the more specific one of how to convert the existing 150,000-volt system into one for 220,000 volts.

The studies have now progressed to the point where a concrete plan of tests is ready to be carried out. This plan naturally takes into consideration separately the line and the station equipment.

Considering first the line, the experiments of Peek, Ryan, and others have provided us with various types of shield rings, the effect of which is to cause a more uniform distribution of potential across the individual units of an insulator string, reducing those most

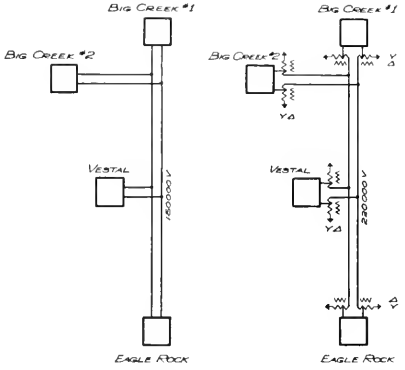


Fig. 1. Connections of Stations for Changing the Voltage of the Southern California Edison Company's 150,000-volt Transmission System to 220,000 Volts. Present connections at the left. Proposed connections at the right, in which each transformer is to have a capacity equal to 100 per cent of its station capacity.

highly stressed and increasing the stress in those carrying less than their proportionate share. With such an arrangement the stresses on the individual units are considerably less at 220,000 volts than at 150,000 volts without the shield rings, as far as fundamental voltages are concerned. The occasional flashing over of insulators on this line has not yet been accounted for, and while perhaps not due to any one cause, the normal line potential probably has little to do with them.

The first logical step, therefore, is to equip one circuit with guard rings throughout, and continue to operate it for a time at 150,000 volts. This will possibly throw some light on the reason for the flashovers.

The next step will be to isolate the lower 40 miles of this circuit and operate it at 220,000 volts energized from some transformers on hand, but not carrying a commercial load, while the remainder continues to operate at 150,000 volts.

There are strong probabilities that this may be all that it is necessary to do, but in case additional length of insulator strings are needed and additional shielding, plans have been made for the modification of the tower tops to provide the increased clearances necessary and further tests will be carried out.

Passing to the various stations on the line, Fig. 1 shows the present arrangement. These stations are all completely equipped for two entering line positions and for double 150,000-volt bus connections inside.

It is proposed to leave the inside of these stations exactly as they are now and to install in the outgoing lines banks of transformers for raising the voltage from 150,000 to 220,000.

These transformers are to be star-connected on the high side and delta on the low. The high side will be arranged as an auto-transformer with 150,000-volt taps on the 220,000-volt winding. The low-tension delta windings will be approximately 30 per cent capacity and be designed adequately to take care of the harmonics, short circuits, grounds, etc. They will be of the simplest possible design and no attempt will be made to utilize them for any other functions.

There will be one bank of these transformers in each line, installed between the line and the station, and each bank will be equal to the capacity of the station. The net effect will be that these transformers will become a part of the line and will be treated as such, and the full capacity of any station can be supplied over either line through the transformers connected to that line.

No switching equipment of any kind will be used on either side of these transformers, and the only instruments will be ammeters in the ground connection.

Fig. 2. Eagle Rock Substation of the Southern California Edison Company

While the capacity of the transformers is spoken of as being equal to the capacity of the station, it must be remembered that their principal function is to act as auto-transformers, and they will be actually only 35 to 40 per cent of the size of those of their actual normal rating. Moreover, they can be designed for maximum efficiency at one-half load and a slight falling off permitted when one bank is carrying the whole load of a station.

This plan has the advantages of low first cost, high electrical and financial efficiency, elimination of high-voltage oil switches of high capacity, and does not disturb or render obsolete any existing plant or investment.

Circular-coil High-voltage Power Transformers

220-kv., 8,333-kv-a. Units for Southern California Edison Company

By Clinton Jones

Transformer Department, General Electric Company

The fact that the circular-coil design of transformer is being used in building the highest voltage power transformers in the world attaches a special significance to this type of construction. In lower voltage ratings, it has already established an enviable reputation. The following article, which is an expansion of one by the author in the *Electrical World*, February 5, 1921, explains wherein it is superior to that of the rectangular-coil design and discusses the details of the construction. A description of the oil conservator tank and the new 220,000-volt bushing is also included.—Editor.

Popular interest in the so-called "super-power" system has been intensified by the coal and oil situation, the war conditions, the recently crippled condition of our transportation facilities, and the probability of further railway electrification. Fortunately, electrical interests have long foreseen the ultimate necessity of higher voltage and larger power transmission systems—such transmission systems as would not only decrease the present waste in undeveloped power but also steadily increase the efficiency of all power in use and relieve the railroads of a vast amount of their present coal-carrying burden.

The movement toward this very vital national economy is being furthered by the enterprise and foresight of individual operators who are so planning and building their systems as greatly to simplify the eventual linking up of what may be termed the "key transmissions" of the various industrial and agricultural areas. The line voltage of 220,000, which has been tacitly agreed upon as being the approximate economic potential for these extensions and interconnections, constitutes a very abrupt step in the curve of maximum transformer voltages, as indicated in Fig. 1. Nevertheless, there is every indication that the use of 220,000 volts will be attended with just as much success as that which characterized the first operation of 150,000-volt apparatus by the Southern California Edison Company. The circular coil concentric winding design is being used for the first transformers and this construction has already proved of great value in the development toward a safer apparatus for very large powers and high voltages. The elimination of the air space in the main containing tank is another noteworthy advance, also the completion and standardization of an oil-filled 220,000-volt bushing to be interchangeable for all apparatus and services with the exception of the line itself.

The last step in potential—namely, to 220,000 volts—had been discussed for some time prior to 1920, but no actual moves were made by the operators until last summer, when the Southern California Edison Company placed an order with the General Elec-

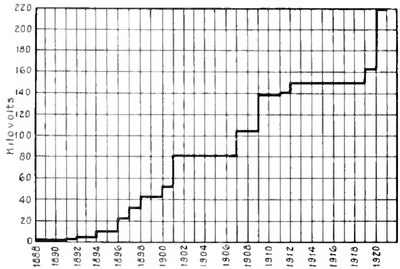


Fig. 1. Curve Showing Increase of Maximum Potential for which Power Transformers Have Been Built Year by Year

tric Company for four water-cooled 50-cycle, 8,333-kv-a. transformers, arranged for operation at 220,000 volts, stepping up from a generated voltage of 11,000. These will be used in the company's new hydro-electric station, to be known as "Big Creek No. 8," which will be a part of an ultimate development for the transmission of 750,000 h.p. at 220,000 volts, over a distance of 240 miles. No definite time has yet been set for operation at 220,000 volts, but it must be in the near future, as the present lines of the Southern California Company will soon be loaded to their full capacity and it is imperative that more power be delivered to Los Angeles County at an early date. This transmission is interesting in that it will be available as a permanent link in the 220,000-volt California bus* by which it is proposed to interconnect all the large natural powers throughout the state.

* Paper by Sorensen, Cox and Armstrong, A.I.E.E., 1919.

[illegible] commercial [illegible] potentials in the [illegible] fact, as far as [illegible] it may be said [illegible] from 150 to 220 kv. [illegible] certainty than did the [illegible] to 100 kv. The recent [illegible] toward the use of the [illegible] with its attendant stabiliza[illegible] potential, has been of great importance in the extension of voltage.

The turning point in coil construction in high-voltage transformer design came after the first experience in potentials from 70 kv. to 100 kv. In order to understand better the needs of the situation, the General Electric Company early in 1910 began extensive investigation of all problems encountered in the operation of several of the early 100-kv. systems. These investigations included the systems of the Colorado Power and Great Western power companies and were very complete and made at great expense. Furthermore, extensive laboratory apparatus was built for experimental purposes, making possible the duplication of phenomena existing in field service and thus permitting more careful and extended investigations. The results obtained were, as is quite usual in such cases, explained without much difficulty by theoretical and practical considerations, and it can be said in all confidence that all of the phenomena inimical to the safety and operation of high-voltage lines and apparatus are quite well known.

Advantages of Circular Coil for High-voltage Transformers

Much has been said in regard to the merits of different typical transformer constructions for high-voltage work, so that it will not be amiss to examine the design of this pioneer 220,000-volt unit. It should be said here that the General Electric Company early committed itself to the use of the circular coil in small form-wound sections for all power transformers. The accumulated experience of the company, both in the early stages of the development of large power units when the "shell" form with rectangular coils was used almost universally and in these later years that have seen such remarkable strides in capacity and voltage, all points unmistakably to the circular coil as the keynote to permanent practice and every danger that still threatens from the use of longer lines with higher voltage and larger powers is closely associated with some important characteristic of design dependent directly upon the form of the coil.

The superior mechanical characteristics of the small circular coil have already proved invaluable in constructing power units which will withstand the destructive efforts of short circuit as demonstrated by actual tests with large powers at the company's Schenectady factory. These mechanical characteristics may be summed up in their larger sense as resulting:

(1) From the fact that a transformer coil under magnetic stress from concentrated leakage flux—i.e., under short circuit—tends to assume a circular form.

(2) From the practicability of assembling such coils with frequent cross-bracing in the direction of the oil flow, thus giving positive support to all conductors at short intervals without interfering with the cooling action of the oil.

The important advance in thermal characteristics made possible by this construction may also be summarized under two general heads—namely, the reduction in heat-blanketing effect of the intercoil bracing structure and the increased cooling efficiency of the oil ducts.

The first advantage accrues from the use of narrow coil and group-spacing braces at right angles to the conductors, thus reducing to a fraction of an inch the length of the heat-conducting path from center of brace to the oil. The second is the result of the very short oil duct in the circular coil assembly, where the oil flow is across instead of along the conductor and the length of the duct is determined by the width of the coil rather than its length. These combined advantages have made it possible to construct large power units in which the "hot-spot" temperature is mainly due to the difference in oil temperature as between the top and bottom coil levels, and this, in turn, can be controlled to a large extent in the design of the particular transformer and its cooling system.

Protection of Coil Insulation from Injury

The protection of turn insulation from mechanical injury both in manufacture and operation is also a noteworthy improvement characteristic of the small circular coil. As this is a very vital detail of any design it will bear brief examination. Such insulation naturally occupies a very restricted space and must stand a high puncture voltage per mil. Uniformity is obviously necessary, and a plurality of thin layers is therefore advisable. The protection of this fibrous insulation in the winding and treating process and the preservation of it in operation has been made much more certain by the use of the small circular coil, which is wound with uniform tension, has no sharp corners and expands and contracts uniformly over the necessary wide range of operating temperatures.

It would be impracticable and out of place here to go into any great detail as to the general merits of the circular coil construction and its adaptability within the commercial range of power transformers. Enough has been said, however, to indicate the basic reasons for the emphasis that the manufacturer has placed on the form of the coil. As the importance of insulation increases the importance of protecting it from mechanical damage or overheating also increases. Thus the natural ruggedness and uniform thermal qualities of the circular coil come into play with increased force. If the oil duct of a low-voltage transformer becomes partially clogged by oil deposit or the distortion of a coil due to magnetic stress, the only immediate effect may be in increase in local heating. If one of these things happens in an extra-high-voltage unit, it may easily cause a breakdown between coils at the next line disturbance.

Again, the circular coil design is exceptionally well adapted to the concentric arrangement between high-voltage and low-voltage windings and this arrangement has been considered by the General Electric Company as being indispensable for extra-high-voltage construction. The value of the concentric assembly may be emphasized under three main points:

(1) It allows of a very important simplification of the major insulation (insulation between high-voltage and low-voltage windings and to ground). This consists of a number of concentric cylinders between the core and low-voltage winding and between the low-voltage and high-voltage windings. These cylinders are highly laminated and are built up on steel forms under high pressure and temperature. They are practically as strong mechanically as the coils themselves and will resist temperatures much in excess of the highest oil temperature which it is possible to employ in transformers. They are so installed with longitudinal bracing as to give a continuous line of support from the outer circumference of the winding to the core. This precludes any movement of parts and closing of oil ducts.

The uniformity and reliability of this arrangement enables the engineer to place much greater weight on other determining factors of design which, in other types, such as the interleaved shell form, must be subordinated to a complicated and bulky system of pressboard collars, group casings, channel pieces, etc., the complete system being repeated between each group of high-voltage and low-voltage members and consisting in total of hundreds of separate pieces for a transformer of extra-high voltage.

(2) With the concentric arrangement great mechanical strength is easily obtained for high-voltage designs. The mechanical support between the ends of the stacks or groups of high-voltage windings and the core frames must be made through some sort of insulating structure which will have a relatively large creepage surface and be of sufficient strength to withstand such short-circuit forces as may be imposed by the design. The principal forces of short circuit result from the crowding of the total flux into the space or spaces between the high-voltage and low-voltage winding groups. In the concentric type, the high-voltage and low-voltage members each consist of a single group on each core leg so that the forces, at right angles to the flux, are radial and are balanced between the coils themselves; while in "interleaved" or "grouped" designs there are a number of high-voltage and low-voltage groups in "sandwich" arrangement on each leg and the forces are axial, thus leaving an unbalanced force at the ends of the stacks.

(3) The single-group concentric design is of great value in preventing the concentration of electrostatic flux from abnormal voltages. The high-voltage coils present an electrically uniform and continuous path for such disturbances, a path which is uninterrupted by the interposition of low-voltage groups as in "interleaved" structures. This uniformity prevents dangerous voltage concentrations due to abrupt changes in the constants of the circuit, changes which become natural reflecting points for travelling waves and nodal points for standing waves.

All [illegible] advantages of the circul[illegible] are well brought out [illegible] under discussion; and, [illegible] arrangement of [illegible] interest as illustrating a novel [illegible] of the General Electric Company for Y-connected permanently grounded units. The sketch in Fig. 2 shows diagramatically the scheme of connections used. It will be noted that the high-voltage line enters the winding at the center of the stacks and progresses in either direction in two multiple circuits to ground. This avoids the necessity of insulating the winding from the core clamps except for the voltage of one coil, and eliminates the striking distances and creepage surfaces which would be necessary at these points for ungrounded transformers or transformers for delta connection. The insulation between turns and coils is graded so as to afford a very high safety factor at the line end where, in this design, abnormal stresses would reach a maximum. It is not necessary to repeat this extra insulation in the body of the windings as might be required with intermixed groups of high-voltage and low-voltage coils.

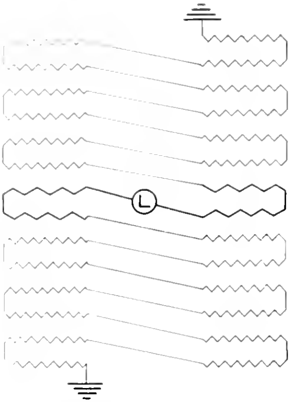


Fig. 2. Connection Diagram of High-voltage Side of 220,000 volt Single-phase Transformer for Y Connection on Grounded-neutral Circuit. Line enters "Buffer Coils" at *L*. The slanting lines indicate series connections between the two core legs. Symmetrical sections in the body of the winding on either side of *L* may be paralleled to provide tap voltages. This diagram is schematic only; it does not show the number of coils or their spacing

The low-voltage windings consist of a single helical coil for each core leg similar to those shown in Figs. 3 and 4. These are wound on ventilated insulating cylinders as illustrated, and are so proportioned with respect to diameter and thickness as to give ample supporting surface and rigidity. They are installed next to the core iron and inside of the high-voltage disc coils. Support is provided at top and bottom by insulating blocks rest-

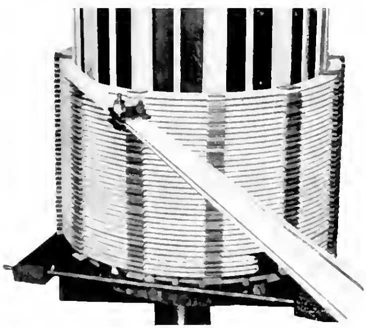


Fig. 3. Helical Low-Voltage Coil in Process of Winding on Insulating Cylinder

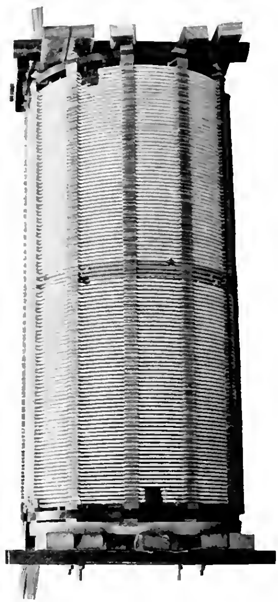


Fig. 4. Completed Low-voltage Helical Coil in Clamps Ready for Varnish Treatment

ing on the core frames. Both the high-voltage and low-voltage coils are of the one turn per layer type, built of round cornered rectangular copper and ventilated and supported throughout by "U" spacers.

The Southern California Edison transformer is of the same general construction as the 10,000-kv-a., 120,000-volt unit shown in Fig. 7 but, unlike the latter, has no porcelain supports at the ends of the stacks, the high-voltage coils resting directly on steel plates anchored to the top and bottom core frames.

The line end of the high-voltage winding, coming from the center of the stacks as shown in Fig. 2, is brought out through a new standard oil-filled 250,000-volt bushing which is interchangeable as between the transformers and high-tension oil circuit breakers. This bushing, Fig. 8, will be interchangeable with any other bushings for 220,000-volt apparatus which may be furnished later. The external shell consists of two porcelain pieces above the transformer cover, one porcelain piece below the cover and an intermediate metal cylinder which is flanged at the upper end to support the bushing. This metal portion always extends below the transformer oil level to avoid any possibility of corona in transformers having an air space between the oil level and cover. A metal tube extends from top to bottom through the center of the bushing, and the intervening space between this tube and the porcelain shell is filled with transil oil and concentric cylindrical insulating barriers. The glass chamber at the top provides space for expansion of the oil and indicates its level. The joints between the shell sections are made with treated cork gaskets compressed locally by numerous bolts engaging metal clamping rings. The central tube serves as the conductor when used in a breaker and as a conduit for a cable conductor in a transformer.

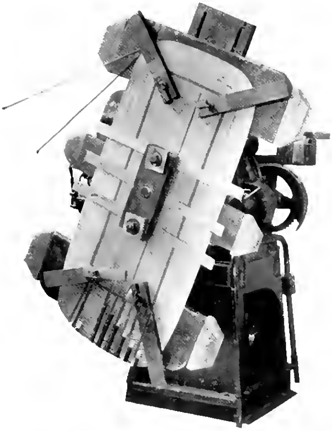


Fig. 5. The Difference in Tension Applied in Winding a Rectangular Coil is Illustrated by the Difference in Lever Arm, i.e., the Difference in the Distances from the Spindle to the Sides. It is impossible to obtain uniform tension in such a coil structure

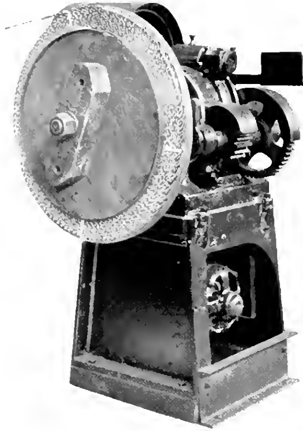


Fig. 6. Uniform Pressure on the Insulation and Tension on the Conductor in all Parts of the Winding is Indicated by the Constant Distance, i.e., the Lever Arm, Between the Conductor and the Spindle of the Winding Form

The bushing has a dry flashover voltage of 660,000. The lightning flashover is estimated at more than twice the normal frequency figure and is equal for wet or dry conditions. In the event of any high impressed voltages the bushing will not puncture but will arc from the terminal to ground without damage. The general design of the bushing is such than an essentially uniform surface distribution of potential is obtained, thus preventing corona on the surfaces.

The containing tank is of the "oil conservator" type, Fig. 9, having a separate chamber for oil expansion. The principles involved in this construction are the elimination of the usual air space above the oil in the main tank and the isolation of the hot oil and tra[illegible] the surrounding a[illegible] it always completely fill[illegible] pressure is prevented by [illegible] tank to the outside air [illegible] device. Any accumulation of [illegible] in the auxiliary tank due to condensation is caught in a sump and may be drawn off through a pet cock at the bottom. This construction eliminates "breathing" in the main tank and keeps the oil absolutely said that the rate of deterioration of the usual organic transformer insulations is greatly reduced by the use of a conservator. Obviously, this is a very important step in advance and can be used to great advantage in high-voltage work.

The total weight of this transformer is 50 tons, including oil. The height from rail to top of bushing is 24 ft. and the diameter is $10\frac{1}{2}$ ft.

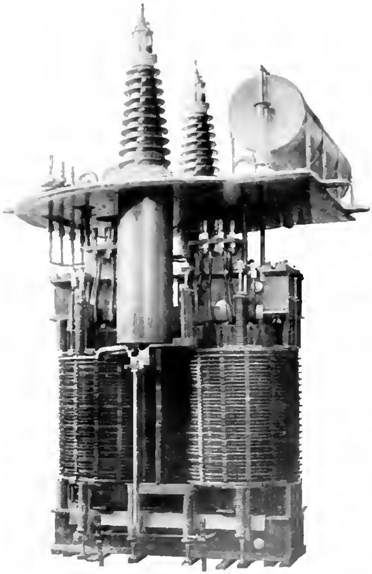


Fig. 7. The 8,333-kv-a., 220,000-volt Transformers for the Southern California Edison Company are Being Built in Accordance with the Same General Winding Construction as Used in This 10,000-kv-a., 120,000-volt Transformer.

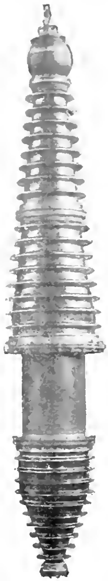


Fig. 8. Oil-filled Bushing Rated at 250,000 Volts Maximum and Standardized for Interchangeable Use on Transformers, Oil Circuit Breakers, and Lightning Arresters

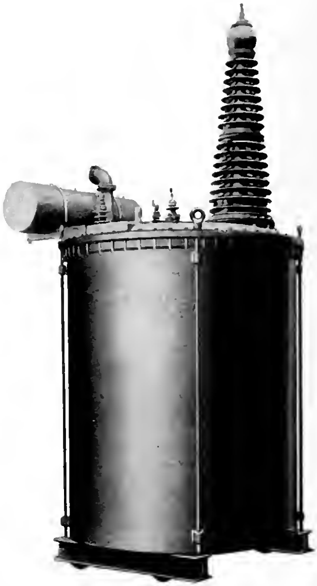


Fig. 9. External View of One of the Four 8,333-kv-a., 220,000-volt Transformers Being Built for the Southern California Edison Company. The oil conservator tank and the new standardized 250,000-volt bushing are shown

dry. It avoids explosions due to a possible mixture of air and gas formed from hot or decomposed oil. It protects the oil from "sludging," which occurs to some extent in all transformers open to the air and is easily accelerated to the danger point during emergency overloads. It preserves the transformer insulations to a remarkable extent, as shown by actual time tests at various operating temperatures. While final conclusions cannot be drawn at present, owing to the protracted nature of such investigation, it can be

A current transformer is mounted on the cover and connected into the neutral circuit before the ground is made on the tank. The current transformers of three units (one three-phase bank) have their secondaries connected in parallel so that any unbalanced current (ground current) can be read.

It is an interesting fact that the manufacturer had actually designed this 220-kv. transformer long before any definite plans had been made by power interests for operation at this voltage.

Economic Aspect of Railway Electrification

By A. H. Armstrong

Chairman Electrification Committee, General Electric Company

The constantly increasing demands which have been placed upon our national transportation system have revealed the facts that the limit of steam railroad practice is about reached and that an extensive changeover to electric operation appears to be the logical solution. The various economic phases of the situation, the short-haul and long-haul passenger and freight service and fuel consumption, are discussed in the following article which was read by the author as a paper at a meeting of the Electrical Section of the Franklin Institute, at Philadelphia, February 24, 1921.—Editor.

An industry valued at some nineteen billions of dollars cannot be ruthlessly tampered with and escape serious economic disturbance, especially when it is closely interwoven with our national prosperity. The story of our railway development is part of the written history of the country. It is, therefore, a matter of grave national concern properly to diagnose the true nature of the ailment affecting our transportation system and to prescribe the treatment of greatest promise for its future recovery.

Necessity for Revising Present Methods of Railroading

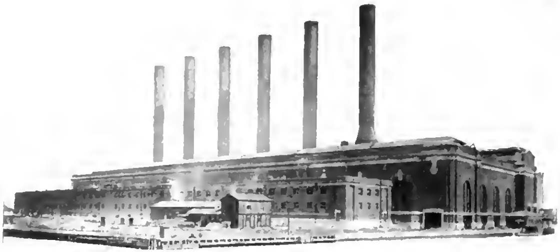
To the great main lines binding East and West, North and South, have been added branches reaching into new country and bringing more products to swell the ever-growing traffic of the parent stem or main line. Engines of greater power have tried to cope with the demands of an increasing traffic and have been assisted by such improvements as heavier rails, automatic air brakes, grade revisions, block signals, and better terminal facilities. Finally, however, when congestion on some main lines became too great with steam engine operation, it was necessary to add a second or even a third or fourth pair of rails.

The limitations of the steam engine are not so keenly felt upon branch or feeder lines with the infrequent small tonnage trains incident to this service. The congestion on main lines has in many cases however become most acute, and it is under such conditions that the steam engine plainly imposes its limitations upon the physical and economic showing of a railway property. Appreciating the need of building new lines into new country to some limited extent, the big problem before us is greatly to improve the railway machine we have already created. We want cheaper and quicker transportation over existing tracks, more reliable service, less congestion at terminals, and proper provision for the future growth of traffic that in the past has doubled every twelve years. This is a large order to place upon steam engine operation, now constituting the foundation upon which our present railway system rests and which many think is one of the fundamental causes of its economic collapse.

We have practically built up our national life around the possibilities and limitations of the steam engine, taking advantage of such improvements from time to time as the advance in its development permitted. But at all times the steam engine has been the determining factor in establishing the entire railway development and has fixed present standards of train loads, speeds, delays, division points, labor conditions, wages, even location of road, and the multitude of factors entering into the vast railway problem. And this big machine has arrived at the point where it costs so much to keep it running that even greatly increased rates will not pay the bill and leave enough over to pay a fair return upon the capital invested. In this respect, a fair return is placed by our government at the modest figure of six per cent of present valuation.

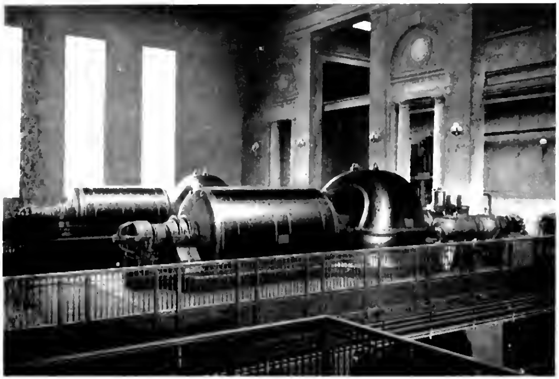
If we are to continue to exchange our eastern manufactured goods for western raw products, the carrying charges over the intervening one to three thousand miles must be kept at a minimum. In no country in the world does one man's labor produce so much, and specialized communities cannot continue to exist as such without the cheapest kind of transportation to facilitate the movement of surplus products from one end of the country to the other. The answer to the present sleeping sickness attacking the prosperity of both railways and industries cannot be found in the merry race of higher transportation rates climbing after increasing labor and fuel costs.

We are facing the facts of an eight-hour basic working day with time-and-one-half for overtime, greatly increased wages, fuel prices at levels never before reached, and maintenance costs that are practically prohibitive. We are told that vast sums of money must be expended on construction and new equipment to make good the deficiencies of the war period and provide for future growth in traffic. But no assurance is offered that such

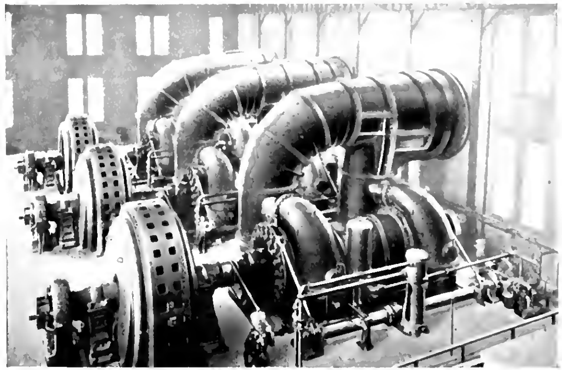


Fisk St. Station, Commonwealth Edison Co.

Great Falls Dam and Power House of Montana Power Co.



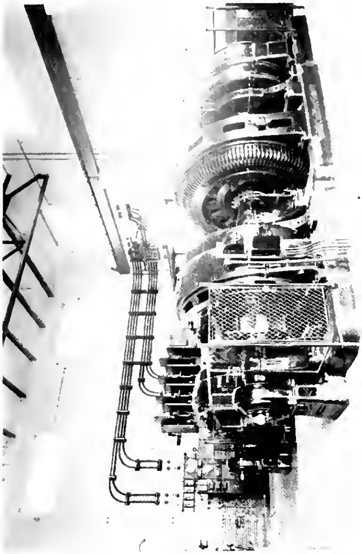
Two 30,000-kw. Turbine-generator Sets, Chester Power House of Philadelphia Electric Co.



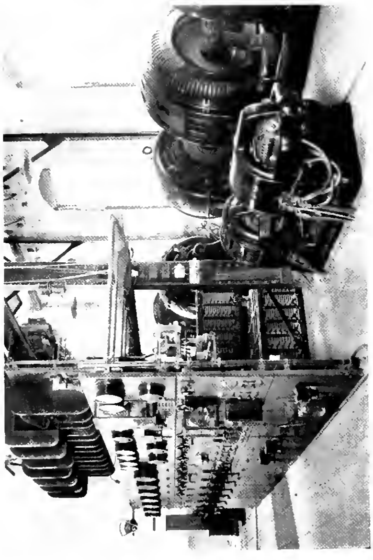
Three 17,400 kv-a. Turbine-generator Sets, Long Lake Development, Washington Water Power Co.

EXAMPLES OF LARGE AND HIGHLY EFFICIENT STEAM AND HYDRO-ELECTRIC GENERATING STATIONS

Montreal Substation, 2400 Volts, Direct Current
Canadian Northern Ry.



Tacoma Substation, 3000 Volts, Direct Current
Chicago, Milwaukee & St Paul Ry



Anaconda Substation, 2400 Volts, Direct Current
Butte, Anaconda & Pacific Ry.

Irvington Substation, 600 Volts, Direct Current
New York Central R. R.

EXAMPLES OF SUBSTATIONS OPERATING STEAM RAILROAD ELECTRIFICATIONS material [illegible] capital account will result in reduced transportation rates, better service, and a better economic return upon a [illegible] already equal in value to our entire national war debt. In fact, it is apparently not possible to make such fundamental changes in railway operation and economics as are evidently necessary to accomplish the desired results simply by investing still greater sums in the old steam engine facilities that have, in the opinion of many, failed to advance with the needs of the times.

Such minor improvements in steam engine design as are already available or in view do not hold promise of any real relief from present operating conditions. The steam engine seems destined to spend the greater part of the year tied to the coal bunker, water tank, round house, ash pit, and repair shop with too little time left for the actual haulage of trains. It is wasteful in man-power, especially on heavy grade divisions, and in these days of high wages and short working hours with severe penalty for delays leading to overtime, this low efficiency in utilizing engine and train crews is fatal to economic success. It is a notorious waster of fuel, burning a quarter of all the coal mined and finally its cost of upkeep and depreciation are so high as to constitute a most serious percentage of the total operating expense.

Perhaps this may seem a rather sweeping criticism of the steam engine. On the contrary, such facts are well known but perhaps not fully appreciated unless compared with the operating records of other types of motive power. The steam engine has held supreme in the railway field for so many generations that to some it seems heresy to question its exclusive right to dominate it for all time.

Motor Truck Competition for Short-haul Freight

During the past twenty years serious competition has entered the field of steam railway transportation. Electric railways have taken over the short-haul passenger traffic and in addition have created travel that never was enjoyed by steam roads. The gasolene motor truck has captured a great part of the short-haul express movement at the expense of both the steam and electric railways. To be sure, this motor truck traffic is partly a left-over from war conditions which demanded quick deliveries, regardless of cost, while it has thus far borne no reasonable portion of public road upkeep. Nevertheless, railways must reckon with short-haul motor truck competition in the future to an extent not as yet clearly defined.

The driver of any "flivver" will declare that he dodges more tonnage carried on motor trucks over main public roads than is in evidence on the railways they parallel. When comparatively small trucks bumping over public highways, not too well maintained at the taxpayers' expense, can successfully compete with rail transportation, something has evidently happened during the past few years which calls for a readjustment of our previous ideas of transportation. It takes a pull of approximately 50 pounds to move a ton over the varying grades and surfaces of our highways. The same 50 pounds pull will haul 10 tons of load over steel rails. Moreover, trucking power is obtained from one of our most expensive fuels and gasolene substitutes are already being eagerly sought after to supplement a product that is fast becoming inadequate to meet the growing demands.

The late J. J. Hill built up the Great Northern property by an early recognition of the fact that while receipts are proportional to ton-miles, operating expenses are determined by train-miles. While efforts to increase train loads were most successful in building up that great property, serving the needs of a new and sparsely settled country, does not the growing competition of the motor truck cast serious doubt upon the wisdom of too close adherence to the same inflexible principle when applied to the conditions obtaining in the congested districts of the East? Admitting the lower expense of train crews with the heavier train loading, is it not possible that the delays inseparable to slow drag freights have materially contributed to establishing the motor truck industry that offers as its one chief asset quick delivery? In his efforts to reduce ever-increasing operating costs, has the railway operator been too busily concerned in running his huge transportation machine to observe fully the industrial needs of the country and to appreciate the evident value placed by the shipper upon speed?

We must admit that the American visiting Europe for the first time is quite likely to look upon its railways as somewhat of a joke. The small cars, light engines and low-tonnage trains contrast unfavorably with American practice as to size. Afterward, however, the interesting discovery is made that most excellent service is given to a densely populated country by these small frequent trains and that American methods would possibly not suit such conditions at all.

It is a wide jump from the motor truck on our public roads to European railways, but can we not learn the same lesson from each—that our present railways do not properly serve the more congested districts through which they pass and that our railway directors have themselves to blame if they do not profit from a recognition of the fundamental facts underlying the growing menace of motor truck competition. Quite evidently our railways as now operated do not provide the service our eastern shippers want.

Shall the short-haul freight traffic be surrendered to the motor truck as was the short-haul passenger business to the electric railway, thus leaving our steel highways free for heavy through train movement only? Can such through traffic alone pay for the upkeep of the property? If not, what steps can be taken to compete for the short-haul business? These are most pertinent questions in view of the fact that many more millions are being spent in building macadam roads and motor trucks than are apparently available for railway betterment.

Electrified Passenger Service in Congested Districts

Electricity has amply proved its effectiveness in the operation of light high-speed trains in congested zones. Steam traditions of a busy track have been shattered by electric train performance. With such successful examples before us as our elevated roads, subways, and electrified railway terminals, there can be no dissenting voice raised to challenge the statement that the adoption of the electric motor introduces the means of making radical changes in steam engine practice in congested terminals. Not only is the electric motor preëminently fitted to meet the needs of short haul, frequent stop service, but it gives opportunity to relocate and redesign the whole terminal railway property along lines impossible to the steam engine.

Contrast the New York Grand Central Terminal of today with that of 1906, before electricity had replaced steam. The air rights over the yards have become most valuable, huge buildings have been erected, adjacent property greatly increased in value and in fact a new residential, hotel, and office center has been created in what may now be called the center of New York City. The Pennsylvania Terminal eliminates the handicap of the Hudson River and the whole picture is rounded out by the growing subway facilities. In fact, New York City is being electrified as regards its passenger transportation and a similar transformation is about to be commenced in Chicago with the substitution of electricity for steam on the Illinois Central Railroad.

Electrified Freight Service in Congested Districts

But that is not all. The way has been shown to solve the equally vital problem of handling freight and express matter in city terminals. The very nature of a steam engine has banished the railway terminal to the outskirts of the city or our cities have developed as far away as possible from an undesirable neighbor. In any case the steam terminal is not immediately adjacent to the shipper or center of distribution, nor is it well adapted to the expeditious and economic handling of freight. Electric terminals, on the contrary, may be located with proper regard to the needs of the shipper, in the very center of our biggest cities if necessary. Tracks may enter terminal warehouses on two, three, or more levels and use but a fraction of the real estate required for an open steam terminal yard. In other words, there are apparently just as great opportunities to effect a transformation in our freight terminal facilities as have already been partly completed in passenger stations and approaches. Furthermore, the solution of the freight terminal problem will go far towards settling the question of short-haul competition and electricity opens the way to overcome the handicaps of the steam engine which is now blocking the further development of the transportation machine.

Wastefulness and Limitations of Steam Operation

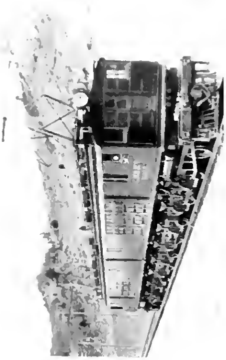
Approximately one quarter of all the coal mined in the United States is consumed by our railways and a great part of this fuel, estimated at possibly one-third of the total, is wasted in so-called standby losses in the 63,000 engines utilized in hauling trains. The modern engine is equipped with all possible improvements designed to increase its fuel efficiency, but nevertheless its main purpose, to which everything else must be largely sacrificed, is to render reasonably reliable service in hauling trains under all conditions of weight, speed, grade, and climatic changes. The fuel economies which it is possible to introduce in a moving structure cannot compare in effectiveness with the developments incorporated in modern electric power stations. The restrictions of track gauge, wheel base, axle weights, and running qualities of the steam engine must impair the effectiveness of its boiler plant. Furthermore, each steam engine is a complete individual power plant subject to all the variations in load incident to hauling trains over a broken profile with intermediate and terminal delays. The boiler must be kept hot at all times, regardless of whether the

Chicago, Milwaukee & St. Paul Ry.

Chicago, Milwaukee & St. Paul Ry.

Philadelphia Rapid Transit Co.

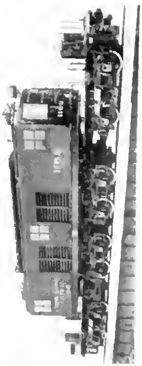
Canadian Northern Ry.



Chicago, Milwaukee & St. Paul Ry.

Fort Dodge, Des Moines & Southern R. R.

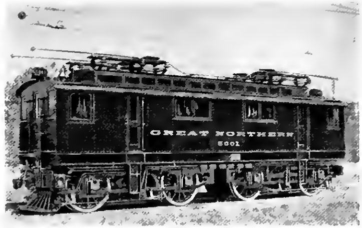
New York Central R. R.



New York Central R. R.

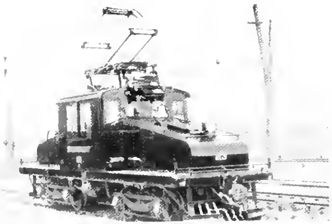
Boston Elevated Ry.


Chicago Elevated Ry.

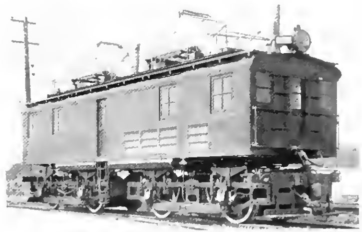


Great Northern Ry.


Interborough Rapid Transit Co.


Hershey Cuban Ry.

Butte. Anaconda & Pacific Ry


Bethlehem Chile Iron Mines Co.


Michigan Central R. R.


Michigan Central R. R.


B. A. & P. Ry. and C. M. & St. P. Ry.

EXAMPLES OF HEAVY TRACTION EQUIPMENT

engi[illegible], thus giving rise [illegible] that form so great a [illegible] total fuel consumed.

Economy and Flexibility of Electric Operation

The electric locomotive on the other hand comprises in the electric motor the most efficient and flexible known means of transferring potential energy into mechanical power. The variations in load of each individual locomotive in operation are largely smoothed out when superimposed upon the average demands of possibly 50 or more other locomotives, with a resulting load curve at the power house supplying them all that is sufficiently uniform to insure the most efficient use of fuel. The steam turbine-generator and auxiliary station apparatus have been developed to such a high state of efficiency that manufacturers' guarantees can be secured of eight pounds of water per electrical horse power. Large power houses are in operation at the rate of 14,000 B.t.u. or approximately one pound of high-grade coal per electrical horse-power-hour output.

Based upon the performance of 60 huge electric locomotives operating over nearly 700 miles of route on the Chicago, Milwaukee & St. Paul Railway and on other facts of record, it has been estimated that the passenger and revenue freight tonnage of the United States could be hauled by electric locomotives for one-third the coal now burned under steam engine boilers. Not even the most ardent electrical enthusiast advocates the immediate electrification of all our steam railways, but the foregoing comparison is offered as a measure of the magnitude of the present wastefulness of burning fuel and the ultimate goal toward which the electrification movement is directed. In this connection, it is of interest to note that railway fuel carried in cars and steam engine tenders equals approximately 20 per cent of the total revenue freight tonnage carried over our rails and practically all of this non-paying tonnage could be saved by electrification. The adoption of electricity therefore would immediately increase the carrying capacity of our railways one-fifth by eliminating the railway coal carrying business from the rails.

Progressive Electrification Policy Abroad

While our country boasts of its almost unlimited fuel reserves and is wasteful to a degree, such is not the condition in other parts of the world. England, France, Belgium, Switzerland, Sweden, Italy, and even bankrupt Austria, all have entered upon an immediate program having for its final objective the universal electrification of the State and privately owned railways in those countries. Shortage of fuel is the most pressing incentive and available water powers will be utilized to the utmost. A constructive government policy makes such an enormous undertaking possible and is in marked contrast to the politics that have brought our own railways to such a sorry financial plight.

Increase of Railroad Capacity by Electrification

In many instances, congestion on mountain grade divisions has reached such a point that additional rails must be laid to obtain the needed relief with continued steam operation. It is in just such service that the electric locomotive offers very great advantages. Drawing power from a practically unlimited source of supply and free from the structural restrictions of the steam engine, the electric locomotive may be built to deliver any tractive power at any speed required by the operating needs of the service. Steam engines are now in operation that will give a maximum draw-bar pull up to the limit of standard draft rigging, but the speed of such powerful Mallet engines is so low as greatly to restrict the rapid movement of freight over heavy mountain grades. Not only can electric locomotives develop equal pull, but sustain full tractive power at double the speed possible with the heaviest steam engine.

Thus while one St. Paul electric locomotive hauls a 3000-ton train up a one per cent grade unaided at a speed of 15 miles per hour, it is quite probable that we may anticipate the early demand for still greater power. Indeed draft gear on commodity freight cars may be so improved at no distant date as to permit hauling a 5000-ton train up a one per cent grade. This would demand a tractive effort of 135,000 lb. at the drivers and an output of the electric locomotive of 5400 h.p. at a speed of 15 miles per hour. Higher speeds at the same tractive effort are entirely feasible; in fact, the manufacturers of electric locomotives would today contract to build such an enormous machine and guarantee its output with no hesitancy as to their ability to make good.

Full appreciation of this fact of the availability in one locomotive structure of power far in excess of anything possible with the steam engine, opens up unlimited opportunities for re-adjustment of present methods of operating our steam roads. In other words, instead of steam engine railroading, as in the past, we are offered the opportunity to enter into an era of real unrestricted railroading with the motive power lid removed.

The development of the more powerful electric locomotive is a determining factor in the matter of grade revision, double tracking and mountain division operation. Not only does the operation of the electric locomotive greatly increase the tonnage carrying capacity of present tracks and postpone for an indefinite period the day of laying additional rails under most difficult and expensive conditions, but it also greatly reduces the hazards of heavy grade railroading by utilizing the so-called "regenerative braking" feature on down grade movement. It is an impressive sight to witness a 3000-ton train being hauled up the 1.66 per cent grade over the divide at Donald and dropped 2000 ft. at Piedmont on the 21 miles of 2 per cent descending grade of the Chicago, Milwaukee & St. Paul Railway without once using the air brakes. The mechanical power developed by the descending train is "regenerated" and returned as electricity to the trolley to be used by some other train, instead of being wasted in the heating of brake shoes and wheels inevitable to the use of air brakes. Besides eliminating much of the risks of grade movement, electric braking contributes to the relief of traffic congestion as it permits using higher speeds on the down grades with safety.

Reliability of Electric Locomotive

One of the marked advantages promptly discovered in the electric locomotive is its great reliability and consequent low cost of maintenance. For a period of ten years, or until the high cost of living struck the electric locomotive as well, the 120-ton New York Central electric locomotives were maintained for approximately 3½ cents per mile run, a noteworthy achievement when compared with the upkeep of steam engines of equal power. Even during the year 1919 the St. Paul electric locomotives, weighing nearly 300 tons and making some 60,000 miles a year, were maintained for approximately 15 cents per mile run, or less than one-third the upkeep of Mallet engines of equal tractive power.

Summary

And so this article could continue to present facts showing the special fitness of the electric motor for the varied needs of rail transportation. While our railways are used for the wholesale movement of passengers and freight, they are nevertheless engaged in the retail burning of fuel under 63,000 individual boilers with the waste inseparable to such a necessity. The adoption of electricity assures such a vast fuel saving that even the most careful estimates appear startling to those who have not studied the facts available.

Electrification of mountain divisions has demonstrated a large increase in single track capacity, estimated by some to be at least 50 per cent greater than possible to steam engine operation. In many instances this improvement can be secured at a less expenditure than would be required for double tracking and also shows a greater return upon the new capital charge incurred.

Cold weather does not affect the electric locomotive at all, in striking contrast to the frozen steam engines of the winter 1917-18, while its greater safety and reliability on grades are matters of record.

Electrified terminals and approaches to large cities should revolutionize present steam engine practice, and not only effect economies in operation but greatly stimulate traffic by introducing radical improvements in facilities. In other words, terminal electrification offers attractive opportunities to both the holder of railway securities and the shipper.

With no immediate prospect in sight of any material reduction in the price of labor, its output must be increased, and electric operation has demonstrated its effectiveness in this direction both on the road and in the shop, together with complete elimination of coal and water facilities, ash pits, turntables, round houses, etc. In addition, locomotive division points may be indefinitely extended and already runs for 440 miles are being made with a single electric locomotive.

All these improvements in the electrified railway property will cost large sums of money. In some items of operating expense, such as fuel, crews, and maintenance, direct savings are effected of such magnitude as to show a reasonable return upon new capital charges incurred in electrification. The argument for electrification, however, is built upon a broader foundation than a direct return upon the investment involved. In fact, it has to do with the vital question of the future growth of our transportation system and its effect upon our national prosperity.

We have come to a period in our railway development where many regard the steam engine as inherently responsible for much of the physical and economic troubles now most painfully apparent. If we may correctly interpret the needs of our railways, they require a major operation rather than the application of a bit of plaster. The steam engine may well retire with full honors from a field which has outgrown it and give way to its younger rival. Youth must be served.

Keeping Steam Turbine Lubricating Oil in Good Condition

By Charles H. Bromley

Technical Director, The Richardson-Phenix Company

[illegible] reviews the severe conditions in steam turbine bearings that have to be contended with [illegible] of a satisfactory system of lubrication. Temperatures are high owing to high steam pressure [illegible], and journal speeds are also high because of the speed characteristics of the steam turbine. No satisfactory lubricant has been found which will not deteriorate with continuous use without purification. However, with the best lubricating oils no bearing trouble should be experienced if proper attention is given to the removal of sediment and moisture. The most economical and satisfactory method of accomplishing this cleansing will depend upon service requirements. The various processes employed, including the batch system, continuous filtration, and continuous by-pass, are described, and in conclusion a list of the requirements of an efficient oil filtration system is given.—EDITOR.

The journal speed in the bearings of a steam turbine is higher than in any other type of prime mover, and although the bearing pressures per square inch are relatively low, nevertheless the high rubbing speed is accompanied by high temperature conducted to the bearings from the steam end. Consequently the film of oil in these bearings must never be broken and, to insure this, all modern steam turbines are equipped with a self-contained oil circulating system. This system provides not only effective lubrication for all of the main bearings and thrust bearings, but it also serves to carry off the heat generated in the bearings, and in some makes of turbines with oil relay governors, oil under pressure is supplied by the circulating system for regulating the speed of the turbine. In cases where the oil film in the bearings of a steam turbine has been broken, due to an interruption in the oil supply, the damage has always been very severe, resulting not only in burned out bearing shells but also in great damage to the blading and spindle, due to the unbalancing effect on the spindle caused by vibration which is set up by the friction in the bearings.

The Trend in Turbine Practice

The trend in turbine design and operating practice imposes increasingly severe conditions upon the lubricant. The tendencies are toward higher steam pressures and higher superheat, giving greater temperatures of the bearings adjacent to the high-pressure end of the unit. Bearing pressures are likely to go up, not down. Modern power plant economics demand that turbines be run for long, continuous periods at or near their most economical load. The number of very large

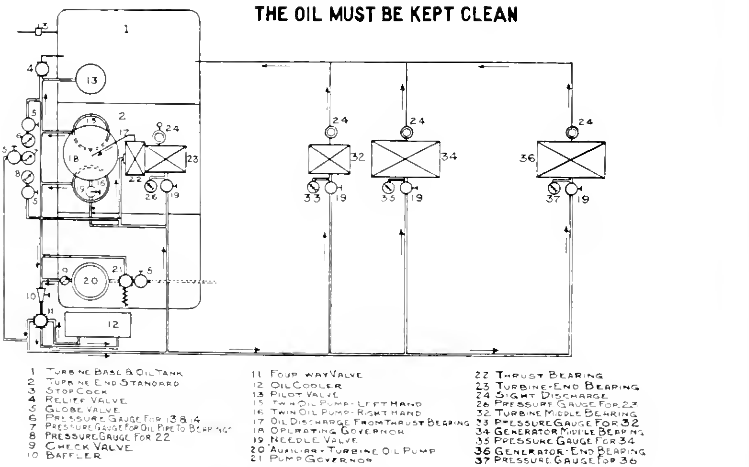


Fig. 1. Diagram of Oil Piping System for Curtis Turbine

From General Electric Instruction Book No. 82221, Page 112 turbines increases owing to the lowering of water rate by size alone up to certain limits, thus the investment in and earning power of such machines must be carefully and adequately insured against shutdowns and damage. This particularly applies to lubrication, which is one of the most vulnerable features of operation. There must be continuously maintained the widest possible margin of safety with the oil.

In view of the foregoing, the makers of steam turbine lubricating oil have concentrated their efforts upon making an oil highly suited to these special needs. Therefore, the problem of continuously maintaining the lubricating oil in first class condition is limited principally to keeping the oil clean and dissipating the heat which it absorbs.

In the early days of the steam turbine, almost unsurmountable difficulties were experienced with lubrication largely due to the kind of oil then used which was not suitable for this severe service.

For the improvement in lubrication which has been made, great credit is due to the leading manufacturers of steam turbines and the manufacturers of high grade lubricating oils.

Turbine Oil Circulating Systems

Today the larger sizes of steam turbines are equipped by the manufacturer with an effective circulating oiling system which can be relied upon to supply an adequate amount of oil to each bearing.

Fig. 1 is a diagram of this form of oil circulating system. The oil is supplied under pressure at the middle of each bearing and flows out at the ends. It returns by gravity to the oil reservoir located in the base of the unit. A rotary pump usually driven from the main spindle of the turbine, but sometimes from an extension of the governor shaft (in the General Electric steam turbine there are two spiral gear oil pumps), takes the oil from the reservoir and forces it through the oil cooler and thence to the piping leading to the bearings.

In the case where the oil is used in the oil relay system for governing the turbine, that for lubrication is reduced in pressure by a reducing valve and delivered through suitable piping and sight feed oilers to the bearings. A relief valve is also provided on the discharge side of the pump to by-pass any excess oil back to the reservoir.

The bearings lubricated by the circulating system on a horizontal steam turbine are as follows: Four main bearings, one on either side of the generator and one on either side of the turbine—and a thrust bearing.

All turbines are equipped with an auxiliary or standby oil pump for the oil circulating system, which may be used when starting and stopping the turbine, or in case of emergency, should the main pump for any reason fail to deliver oil at the required pressure and volume. In some cases a duplex steam pump is used and on General Electric turbines a turbine driven pump is furnished.

A pump governor (or regulating valve) is placed in the steam feed pipe leading to the auxiliary pump. The valve of the governor is actuated by the oil pressure in a small pipe connecting the governor to the high pressure pipe of the oiling system, and automatically feeds steam to, and actuates, the auxiliary turbine oil pump, in case the oil pressure drops below the pressure for which the regulating valve is set.

Steam turbines operate at high speed, as many of the advantages are secured from this feature. Therefore, great care has been exercised in the design of the bearings. Especial attention must be given to the selection and care of the lubricating oil. Properly lubricated a high speed bearing will not cause any more trouble than a low speed bearing. The oil pressures vary from 2 lbs. to 15 lbs. per square inch for the bearings, depending upon the make and type of the turbine. The temperature of the oil in the bearings sometimes reaches 180 deg. F.—the normal operating temperature being about 130 deg. F. The oil should be a pure petroleum product properly refined and should be made without the admixture of any compound not derived from crude petroleum. The flash point in an open cup tester should not be below 315 deg. to 335 deg. F. and the viscosity at 100 deg. F. should range from 150 to 310 seconds Saybolt viscosimeter, depending on whether an extra light, light or medium oil is used.

High Factor of Safety with Clean Turbine Oil

Most engineers in charge of turbine plants are careful to select the best turbine lubricating oil, but unless this oil is kept in good condition its lubricating value soon drops below that of a low grade oil. It is therefore obvious that it is best to purchase the highest grade of steam turbine oil and also to provide means to keep it in first class condition continuously.

Of course, one may point to turbines long installed in which the oil, occasionally sweetened and renewed periodically, is apparently in good condition and the margin of safety with it seemingly wide. But just so one may refer to reciprocating engines which a few years ago were operated without oiling and filtering systems whereas now practically all [illegible] systems. There [illegible] that have long been [illegible] damage; their factor of [illegible] it is the largest factor of [illegible] prudence dictates. With [illegible] as sweetening, batch filtering

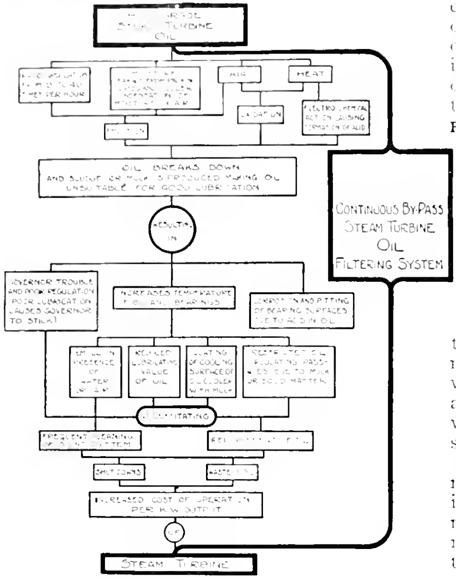


Fig. 2. Chart Showing Step by Step the Various Agents Constantly at Work Which Destroy the Lubricating Value of Oil, the Troubles Resulting, and How They Can be Prevented

or any system of treatment which dilutes instead of continuously keeping the oil free from impurities, long runs without trouble may be the engineer's good fortune; but he has no such insurance against the day of sudden unexpected trouble as he has when purification is continuous.

The troubles encountered in an oil circulating system are shown graphically in the chart, Fig. 2. Assuming that the lubrication of the turbine is started with a high grade oil of the above specifications, we will analyze point by point the possible sources of trouble.

The first of these which tend to cause a breakdown of the oil is the rapid circulation. This varies from 7 to 10 times per hour in different sizes and makes of turbines. This rapid circulation does not give the oil an opportunity to precipitate any moisture or foreign matter picked up in its circulation nor does it permit the elimination of air which may have found its way into the oil.

In a closed continuous circulating system it is impossible to know from the outside the exact condition of the oil and whether moisture or impurities are present. Even if samples of oil are taken from the system at frequent intervals and analyzed, the result would show only an approximation of the average condition of all of the oil.

Formation of Emulsion and Sludge

Moisture finds its way into the oil in a number of ways in spite of the precaution taken by manufacturers in the construction of packing glands. These glands are sometimes fitted with carbon packing rings held against the shaft by springs, labyrinth packing or water seals, or water throwers introduced between packing glands. Some moisture also gets into the oiling system when the turbine is at rest, due to condensation of moisture in the air when it comes in contact with the cool metal surfaces of the turbine and oiling system. Another way in which water may get into the system is through small leaks in the oil cooler.

In turbines where the bearing shells are made hollow and cooled by circulating water, if there is any leakage in these shells water may also enter the oiling system in this manner. The combination of water, air, heat and the rapid circulation of the oil causes it to oxidize and readily form an emulsion, in which a brownish or light chocolate colored sediment is produced, most of which remains in suspension in the circulating system if not continuously removed. It is important that not too heavy an oil be used so that no heat is generated due to the internal friction of the oil itself (fluid friction), because this will not only cause oil trouble, but also a loss in power.

An emulsion is a mixture of liquids, insoluble in one another where one is suspended in the other in the form of minute globules, or it is a mixture in which air or solid particles are suspended in a liquid. In a system in which the oil is rapidly circulated an emulsion is easily formed because of the mixture with either air or moisture, which reduces the lubricating properties of the oil, resulting in poor lubrication and the accompanying rise in bearing temperatures. If water and air are continuously removed and do not accumulate an emulsion cannot form.

One of the most common causes of trouble in lubricating a steam turbine is due to emulsification of the oil, particularly if other impurities such as solids, that is, grit and dirt are present. This emulsification takes up dirt, particles of metal, and other foreign substances and holds them in suspension so that they cannot readily precipitate.

Emulsion increases at an accelerating rate once a small amount has accumulated and finally becomes so thick that a sludge or muck will settle out and deposit on the cooling coils, in the oil passages and cause a dangerous rise in temperature of the entire body of oil in the system.

Acidity

It is known that the first step in the deterioration of steam turbine oil is the formation of organic acids caused by oxidation of the unsaturated compounds containing sulphur, nitrogen and oxygen. This oxidation is greatly assisted by the presence of small particles of oxidized metals, dirt or dust; apparently they act as catalytic agents, absorbing oxygen and feeding it to the oil. The organic acids being subjected to heat and pressure are polymerized into both soluble and insoluble matter.

Furthermore during the treatment of the oil with sulphuric acid in refining the so-called sulphonic acids are formed and unless these are entirely removed in the subsequent refining operations they will be broken down by the action of water, one of the resulting products being sulphuric acid.

The presence of sulphonic acids increases the rate of oxidation of the oil and this in turn increases the tendency to form emulsions with water. The presence of any catalytic agents such as particles of oxidized metals, dirt or dust, in addition to moisture, results in organic acids being formed at a constantly accelerating rate.

Many turbine operators are greatly disturbed about the acidity of the oil. There will be no occasion for this if the oil is kept continuously purified during use. Analyses of oils from many turbines show that where this continuous purification is carried on, the acid content of the oils after years of service is less than 1 per cent. The explanation is that the acid is entrapped in impurities in the oil, and the continuous removal of these keeps down the acid content.

The manufacturers of steam turbine oils have carefully studied the requirements of the service and have consistently followed the subject through their technical departments, obtaining data in the field as to the results of the service which their oils gave

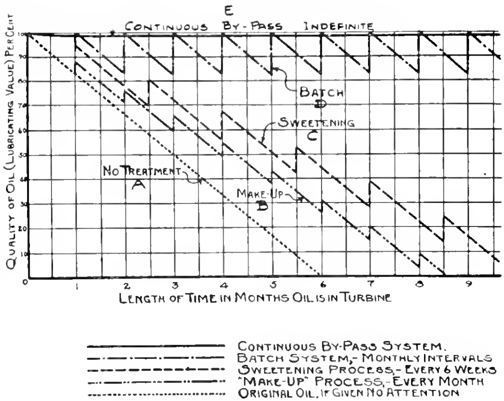


Fig. 3. Curve Showing Results Obtained from Various Methods of Purifying Steam Turbine Oil

and which have finally resulted in there being produced the very best oils for these conditions. This is a big step forward, but it must be supplemented by the use of an oil clarifying system to operate in conjunction with the circulating system of the turbine, so that the oil will be continuously kept in good condition. A number of methods of maintaining the quality of the oil have been tried and the following shows step by step how finally the solution of the problem was reached.

Adding "Make-up" Oil and "Sweetening"

To make up for the amount of oil lost by evaporation and leakage, or withdrawing from the turbine oil reservoir a certain amount of oil periodically and adding enough new oil to replace the amount withdrawn were the first steps used in an endeavor to keep the oil in good condition, but it was found that these methods were not effective, because the impurities, emulsion, sludge, etc., were not removed but merely diluted.

Referring to Fig. 3 which shows graphically the results of various methods of purifying turbine oils, Curve "A" indicates the deterioration of the oil without any attempt at purification. Assuming that new oil has 100 per

...lubricating value and is used continuously without any attention. Curve "A" indicates what will happen. The lubricating value of the oil will decrease until the danger point has been reached and it has to be removed and new oil put into the system. Adding make-up oil slightly prolongs the life of the oil as shown in Curve "B." Curve "C" shows the results of "sweetening," which is a little more effective than "adding make-up," but it is only a question of time (using either one of these methods) before the whole charge of oil is unfit for use because the impurities are not removed but merely diluted.

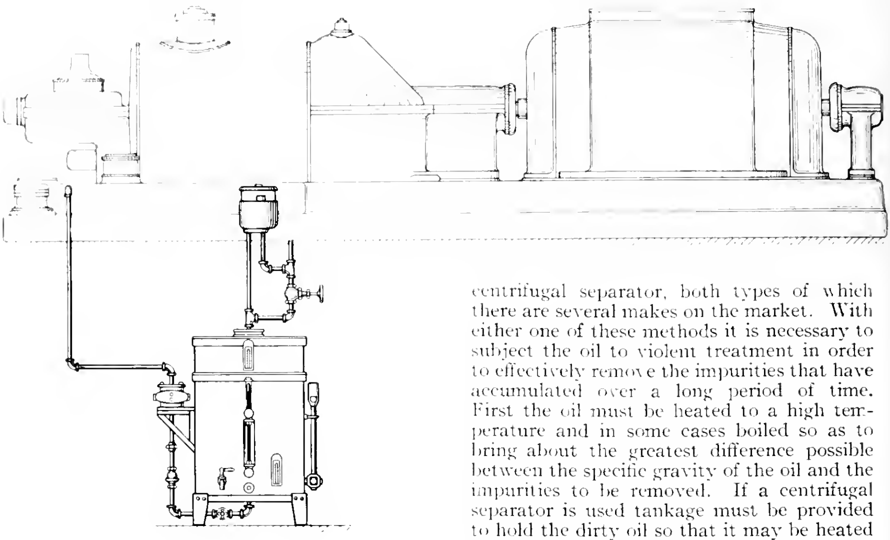


Fig. 4 Continuous By-pass Oil Filtration System

Batch System

Curve "D" shows the results of batch filtration which is a pronounced improvement over methods "B" and "C" as the entire oil charge of the lubricating system of the unit is drained at definite intervals, or when, in the judgment of the operator, it is found necessary; a fresh supply of clean oil is introduced and the used oil is submitted to a filtration and purification process in which heating of the oil to high temperature, precipitation, chemical treatment, etc., are necessary.

This system presents several objectionable features: It is necessary to shut down the unit each time the oil is changed—this operation being left to the discretion of the turbine operator and must be scheduled in accordance with the requirements of the service. Invariably there is kept in the lubricating system for an excessive length of time an oil unfit for use, with considerable risk of endangering the turbine. Furthermore, this system being intermittent, the duties necessary to its operation cannot be performed by the personnel as efficiently as if they were assigned to a group of men continuously engaged in this work.

Batch filtration is accomplished in two ways, i.e., by means of a gravity type oil filter or a centrifugal separator, both types of which there are several makes on the market. With either one of these methods it is necessary to subject the oil to violent treatment in order to effectively remove the impurities that have accumulated over a long period of time. First the oil must be heated to a high temperature and in some cases boiled so as to bring about the greatest difference possible between the specific gravity of the oil and the impurities to be removed. If a centrifugal separator is used tankage must be provided to hold the dirty oil so that it may be heated and also additional tankage to hold the oil after it has passed through the separator.

When considering the question of purifying used turbine oil, the average engineer always has in mind oil in its very worst condition, that is, when it is full of impurities, badly emulsified and loaded with muck or sludge, and rightly so because in the past it has been common practice to remove the oil only when it reached this dangerous condition.

By a simple method the moisture and other impurities which cause emulsification and sludge and deteriorate the lubricating value of the oil can be continuously removed. Emulsion cannot take place if the impurities which cause it are removed as fast as they occur and sludge will only form as the emulsion builds up. Sludge is the product of emulsion in the form of a thick and viscous coagulation which retains most of the impurities which have come in contact with the oil. If emulsion is prevented sludge will not form.

Continuous Filtration

In this system the oil leaving the bearings is filtered before it is returned to the turbine oil reservoir and is most positive and effective in maintaining the quality of the oil. The objections to its use, especially for large units which require a great volume of oil are the size of the filtering equipment and oil pumps and the space they occupy as well as the cost of installation.

Continuous By-pass System

Curve "E," Fig. 3, shows graphically what is accomplished with this type of system and which makes it possible to use the oil continuously and maintain its lubricating value equal to that of new oil. Thus oil of the very highest grade and price can be used economically because the oil in the system becomes an investment rather than an expense. A small amount of oil must of course be added from time to time to take care of losses due to vaporization, leakage, etc., but what the limit of useful life of a turbine oil is when purified by this continuous by-pass system is not yet known. Turbines equipped with this system have been in service for 2½ to 3 years continuously using the original oil with slight make-up added and at the end of such periods there is no deterioration in lubricating properties as is shown by the following analyses:

Plant: Eastern Wisconsin Electric Co., Sheboygan, Wis.

Turbine: 6000 kw.

This turbine has been running practically continuously 24 hour day service for 2½ years.

Lubricating Oil: "Superla" (Standard Oil Company).

Lubricating oil purification system: Continuous By-pass.

	New Oil	Same Oil After 2½ Years Continuous Use
Specific Gravity, Deg.	27.8	27.6
Flash Point, Deg. F.	322	324
Fire test, Deg. F.	390	393
Chill test, Deg. F.	30	31
Viscosity at 100 deg. F. sec. Saybolt	138	139
Acidity		0.25%

Lack of space forbids quoting additional analyses, but the above is illustrative of the results obtained.

Referring to Figs. 4 and 5, which show the application of the continuous by-pass system, the first impression is that of its extreme simplicity, consisting of a gravity oil filter, an electric or steam driven oil pump, a vented sight overflow fitting and a small amount of pipe and fittings. The system is fool and trouble proof as stoppage of pump or filter or both simply leaves the turbine to operate the same as it would without the system. The oil level "A" in the turbine oil reservoir is automatically maintained, as the level of the top of the overflow pipe "B" is permanently set to correspond to the desired level of oil in the turbine oil reservoir. The outflow of oil to the filter is positively controlled by the amount of oil delivered to the turbine oil reservoir from the filter, the overflow fitting being vented to prevent syphoning.

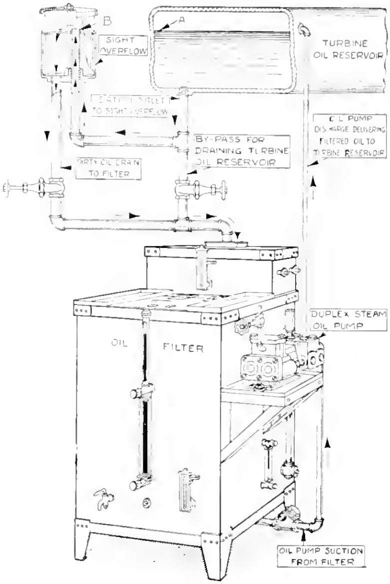


Fig. 5. Part Sectional View of Turbine Oil Reservoir Showing How Oil Level is Maintained

[illegible] application of this [illegible] two 15,000-kw. General [illegible] installed in 1918 at the [illegible] the Turners Falls Power and [illegible] Company, Chicopee Junction, Ma[illegible] overflow fitting beneath

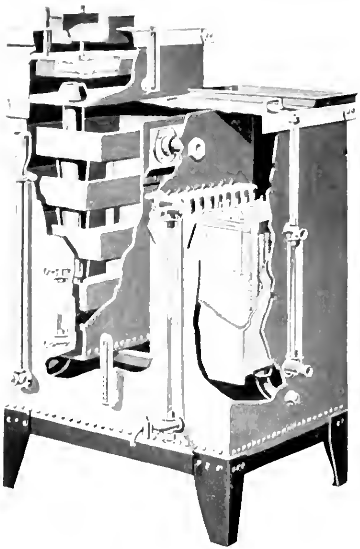


Fig. 6. Sectional View of Oil Filter

the main bearing. In the basement below is located the oil filter, back of which is the motor driven oil pump which returns the filtered oil to the turbine oil reservoir. Each unit in this plant is equipped with this system.

The reason this system has proven so successful is that it continuously removes the agencies which if allowed to accumulate would cause the oil to emulsify and break down. With proper oil and a clean circulating system there is no deterioration of the oil because the circulation is so rapid (keeping impurities in suspension) and purification of the whole oil charge so frequent that no sludge or muck accumulates, all the oil in the system passing through the filter once every hour. Analyses of the oil taken from the turbine oil reservoir or any part of the circulating system shows that it is all of good uniform quality with lubricating value equal to that of new oil.

By continuous purification, the total content of solid and liquid impurities distributed throughout the large volume of oil in the system is so small as to be negligible.

The oil contained in the filter increases the total amount of oil in the system and this increased volume results in less work per gallon of oil and a reduction in temperature. It also provides an effective safety device in case of excessive water leakage into the system and is insurance against lubrication trouble at a cost which is insignificant when compared with the cost of the turbine which it protects.

Coefficient of friction and bearing temperature tests in comparing new and filtered oil are the best indications of their relative values as a lubricant.

No practical or commercial method of filtering lubricating oil will absolutely remove every trace of solids or moisture as fast as they appear (as laboratory tests will show) but this is neither necessary nor desirable, because after all what we are striving for is a practical, inexpensive method of treating oil so that its initial lubricating value will remain constant.

Lubricating and filtering systems for reciprocating steam engines and auxiliaries are usually open systems, where the losses due to splashing, leaks and evaporation are large and impurities from the surrounding air get into the oil. With steam turbines, the systems are closed, and impurities from the air can be kept down to an almost negligible minimum. Because turbine systems are closed, the loss of oil due to evaporation, leakage, splashing, etc., is considerably less, although the oil is worked very much harder. Therefore, a unit volume of oil put into a turbine system and continuously purified will give materially longer service than the same volume will when used on any other type of prime mover.

About 400 steam turbines ranging from 200 to 60,000 kw. have been equipped with this system, many of which have been in operation for several years, giving very satisfactory results. One manufacturer of steam turbines has adopted it as standard equipment.

Requirements of an Efficient Oil Filter for Purifying Steam Turbine Oil

It should operate on the dry principle, that is, the oil in its course through the filter should not pass through water.

Liberal precipitation area is required so that the oil flowing at a low velocity will precipitate entrained water and the heavier foreign particles, which should be by-passed to the bottom where they cannot again enter the oil.

The precipitation compartment should have an automatic water ejector of sufficient size to remove the water precipitated without carrying oil with it.

The cloth filtering elements should be free from plaits or folds and preferably arranged vertically so that the foreign matter will continually work toward the bottom and drop off, thus automatically tending to keep the filtering surface clean. The hydrostatic head on the cloth should be low so that suspended solids are not pushed through.

A widely used oil filter having the above requirements is shown in Fig. 6, its operation being briefly as follows:

The process of purification is accomplished both by precipitation and by filtration through closely woven cloth. By the former process oil is brought practically to rest and entrained water and heavy particles of foreign matter are allowed to settle out.

1. The incoming oil is heated when necessary to lower its viscosity and thus reduce its ability to retain water and solid particles in suspension.

2. The oil then takes a long path, flowing at a low velocity over shallow trays where precipitation takes place.

3. The oil then flows under a 3-in. hydrostatic head through the filtering medium, every square inch of which is effective and subject to equal pressure.

4. The oil passes into the clean oil compartment ready for re-use.

In any system of turbine lubrication the end sought is not so much economy in oil as protection of the investment which the prime mover represents, and this insurance, if there is to be minimum oil consumption, obviously depends upon the thoroughness with which the filter does its work.

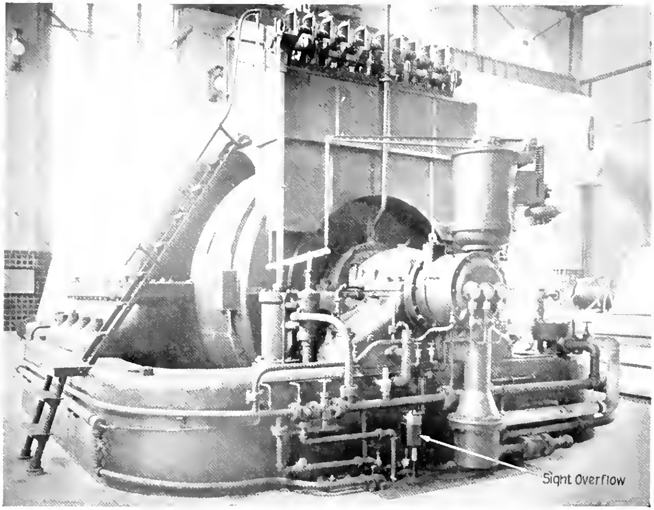


Fig. 7. 15,000-kw. General Electric Turbine Equipped with Continuous By-pass Filtration System

Some Methods of Obtaining Adjustable Speed with Electrically Driven Rolling Mills

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[illegible] of steel rolling mills, disclosing the need in many cases for adjust- [illegible] the merits of the Scherbius system of speed [illegible], in which the [illegible] energy of the main motor is returned to the [illegible] Kraemer, or synchronous converter system, in [illegible] main motor shaft. The superiority of the Scherbius system is [illegible] synchronism, as over this range the synchronous converter of the [illegible] Scherbius system permits of satisfactory operation [illegible] synchronism. This range is not practicable with

[illegible] EDITOR

Speed Requirements of Rolling Mills

It may be of interest to those who are not familiar with steel mill rolling practice to review briefly some of the more important considerations which affect the speed of rolling before discussing the different systems of obtaining the required speed control. Obviously economic considerations demand that the steel shall be rolled at the maximum speed possible without adversely affecting the quality of the product.

The speed at which the steel will enter the rolls is affected by the diameter of the rolls, the weight and cross section of the piece, and the extent to which the rolls are ragged. For the same pair of rolls, the smaller the section and the lighter the piece the higher the speed at which the rolls will grip it.

Once the piece has entered, the maximum speed at which it can be rolled is determined by its section and by the draft. It is essential with large drafts, especially for cast ingots, that the speed be low to allow time for the steel to flow. The speed is also affected by the type of mill, the method of handling the steel, and the weight of the piece.

In rolling shapes, especially certain ones, the amount of waste is greatly affected by the speed. If the speed is too high the steel will not flow into the corners and if it is too low it will flow out between the rolls, producing a "fin" which cannot be rolled in by subsequent passes.

Increasing the speed for smaller sections not only increases the production but decreases the power consumed per ton rolled, because of the higher average temperature maintained during rolling. Obviously the best speed is frequently a compromise between opposing factors and differs with almost every section, making it advantageous and often necessary to provide adjustable speed control for mills rolling a variety of shapes.

While the installation of large mills limited in their production to a comparatively small range of sections has tended to reduce the advantages of adjustable speed operation, the ever increasing roll speeds have had exactly the opposite effect and we find a constantly increasing demand for equipments capable of being operated over a considerable range in speed. Not only this, but the speed requirements become more and more exacting as to refinement of control.

Motor Speed Nomenclature

The difficulties encountered by the electrical engineer in obtaining an adjustable speed motor are not always appreciated by the steam engineer or operating man who is familiar with the characteristics of the steam engine, which is naturally a variable speed machine to which special control devices must be applied to give it constant or adjustable speed characteristics, while electric motors of the type applicable to steel mill main rolls are essentially constant speed machines. Throughout the paper the terms adjustable speed, multi-speed and varying speed are used, and in order that there may be no misunderstanding as to their exact meanings their definitions as given by the Standards Committee of the A.I.E.E. are included here.

Adjustable speed motors are those in which the speed can be varied gradually over a considerable range, but when once adjusted remains practically unaffected by the load.

Varying-speed motors are those in which the speed varies with the load, ordinarily decreasing when the load increases.

Multi-speed motors are those which can be operated at any one of several distinct speeds (these being practically independent of the load), but which cannot be operated at intermediate speeds.

Essential Motor Characteristics

Just what are the essential characteristics of an adjustable speed motor?

First, it should embody all the characteristics—strength, rigidity, reliability, safety, and accessibility—of the constant-speed induction motor which have been such large factors in the success which has attended the application of these motors to rolling mills.

Second, when adjusted for any speed throughout the range of control the speed should be only slightly affected by wide variations in load.

Third, it should be capable of carrying high overloads, 125 per cent to 150 per cent, throughout the full speed range.

Fourth, its efficiency should be highest over the range of speeds required for the greater part of the production.

Fifth, if any of the alternating-current types is used its power-factor should be high.

Sixth, its cost must not be excessive.

At the time when motors were first applied to main rolls, four methods of obtaining adjustable speed control were available, all of which had been thoroughly tried out in other fields, viz.:

Adjustable speed control with direct-current motor, in which the speed of either a shunt or compound wound machine, taking power from a constant potential source, is changed by varying the strength of its field.

Adjustable speed operation by the so-called Ward Leonard system of control in which the speed of a shunt or compound wound direct-current motor is varied by varying the voltage

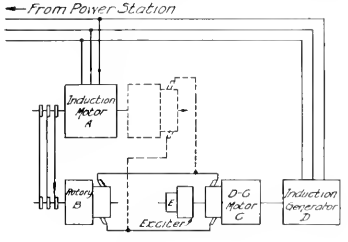


Fig. 1. Kraemer System

impressed on its armature, at the same time maintaining its field constant.

Multi-speed control with changeable pole motors in which induction motors are used having two or more independent windings designed for different synchronous speeds, or with a single winding so arranged that the number of poles can be changed at will through switches external to the machine.

Multi-speed control with induction motors operating in concatenation. As applied to main rolls, concatenated motors consist of two mechanically connected single speed or

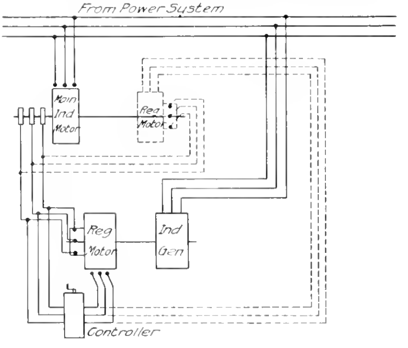


Fig. 2. Single Range Scherbius System

multi-speed induction motors so connected electrically that the mill may be driven at the synchronous speed of either, or at a speed corresponding to the synchronous speed of a motor having a number of poles equal to the sum of the poles of both machines.

Direct-current Motors

From the standpoint of speed control alone, the adjustable speed direct-current motor with motor field control or with Ward Leonard control meets steel mill requirements, but these motors are usually expensive and low in efficiency as they require a motor-generator or synchronous converter to transform the alternating current of the general supply system to direct current. The loss in power due to the conversion varies from 10 to 20 per cent depending upon the size and type of converter and the nature of the rolling load cycle.

While direct-current motors can be and have been so designed as to operate entirely successfully when driving main rolls, the commutation problem is a difficult one and the vibration and dirt which are always present aggravate the sparking at the high overloads and make it difficult for the commutator to take on a polish. On the other hand the use of the single speed induction motor under the most adverse conditions of load and dirt has demonstrated its superiority as a main roll drive.

Development [illegible] Satisfactory Induction Motor Drive

I[illegible] re natural to find mill men a [illegible] making every effort to adapt [illegible] mill [illegible] induction motor speed characteristics. Where the range of sections was [illegible] as to require different speeds, two or

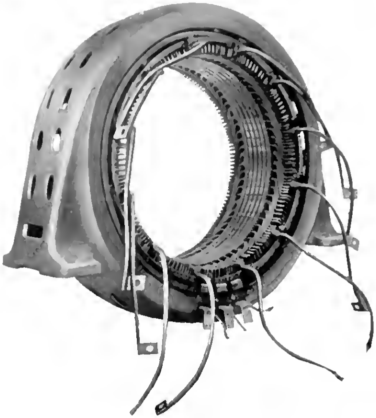


Fig. 3. Completely Wound Stator of Scherbius Regulating Machine

three compromise speeds were chosen and multi-speed motors purchased. But at best these motors are inflexible, their use almost always entails a sacrifice, and especially with 25-cycle power it is difficult to obtain speeds which are sufficiently near the desired speeds.

Appreciation of these facts led many of the leading engineers, throughout Europe as well as in America, to devote considerable time and expense to the study of the problem of making an alternating-current motor which would embody the mechanical characteristics of the induction motor, the speed characteristics of the direct-current adjustable speed motor, and to have an efficiency which would approach that of the multi-speed induction motor. Many systems were suggested and a few actually found their way into steel plants, although by far the greater number have passed into history with only a patent office record.

The Scherbius and Kraemer Systems

Of the systems developed, two embody to a more or less degree the desirable characteristics of an adjustable speed mill motor. These are commonly known as the Kraemer or synchronous converter system and the Scherbius system. In both of these systems the slip energy of the induction motor which is ordinarily thrown away as heat in the rheostat is returned either as electrical energy to the general power supply system or converted to mechanical power through a motor mounted on the same shaft with the main

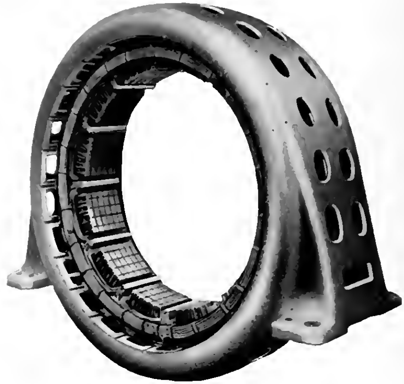


Fig. 4. Partly Wound Stator of Scherbius Regulating Machine

induction motor. Diagrammatically these two systems are shown in Figs. 1 and 2.

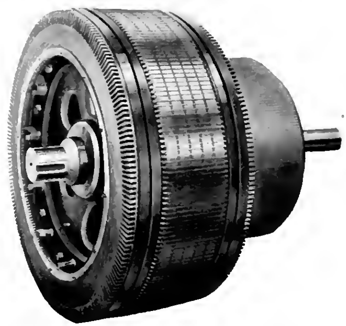


Fig. 5. Completely Wound Rotor of Scherbius Regulating Machine

At standstill the voltage across the slip rings of an induction motor is that corresponding to its ratio as a static transformer, and the frequency is that of the system supplying current to the stator. At synchronous speed the slip ring voltage and frequency are zero

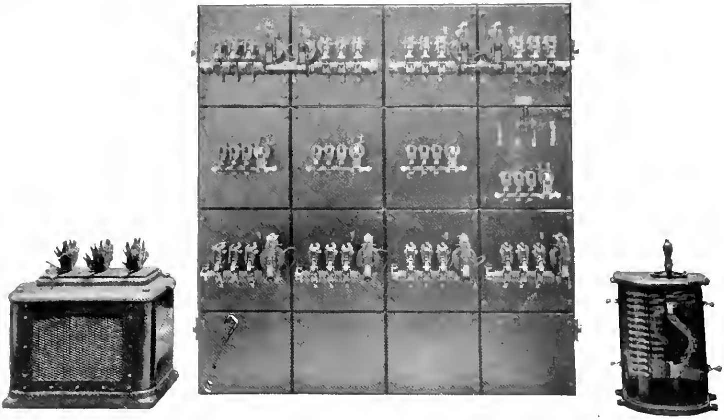


Fig. 6. Speed Control Equipment for Scherbius System

and at all intermediate speeds they are proportional to the per cent slip, or $\frac{1-\text{speed}}{\text{speed}}$. In the Scherbius system the counter e.m.f. of the regulating motor which is connected across the slip rings of the roll motor opposes the slip ring voltage, and as the counter e.m.f. of the regulating motor is raised and lowered by varying its field the speed of the roll motor is lowered and raised correspondingly (single range equipments assumed). With this change in the speed of the roll motor, the rotor frequency varies also as stated before.

The stator of the regulating motor of the regulating set resembles an induction motor stator in appearance, although its punchings and windings are quite different. (See Fig. 3.)

The field windings resemble those of a direct-current machine with distributed windings, having main and commutating poles

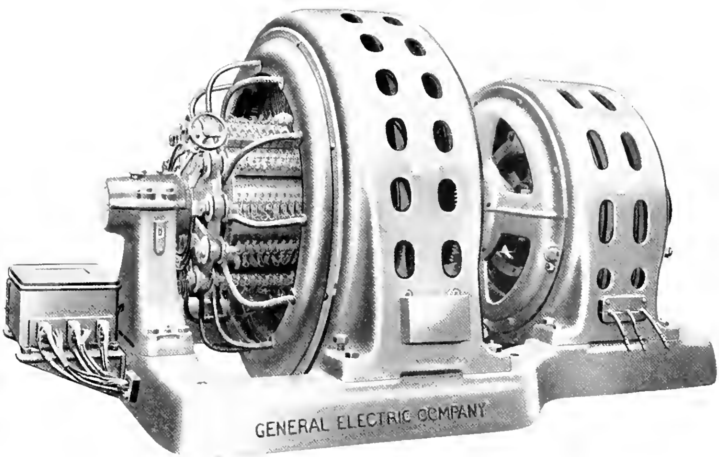


Fig. 7. Scherbius Regulating Set

[illegible] Fig. 4. The ex- [illegible] through a compen- [illegible] main motor and [illegible] different taps on the [illegible]

[illegible] that of a direct- [illegible] shown by Fig. 5. [illegible] contactor panel and [illegible] taps are shown in [illegible]

The regulating motor drives a generator which can be either of the synchronous or induction type, but owing to the simplicity of the latter it has been universally used. (See Fig. 7.)

In principle the Kraemer system is similar. The counter e.m.f. of the synchronous converter, which is varied through the field of the d-c. regulating machine mounted on the roll shaft, opposes the slip ring voltage. The synchronous converter and direct-current motor on the main roll shaft or motor-generator resemble in appearance and construction standard units of these types as is shown in Figs. 8 and 9.

While usually the slip energy of the roll motor may be converted either to mechanical power or returned as electric energy, one or the other method is usually preferable, the choice being affected by the speed of the main motor and the nature of the load over the range of speed control; that is, whether the horse power is proportional to the speed

Constant torque (1000 h.p. approx. syn. speed) with motor generator.

Slip (s)	.05	.10	.20	.30
Energy returned at B	50	100	200	300
Output of main motor	950	900	800	700
Input to main motor at A	1000	1000	1000	1000
Net input to system at C	950	900	800	700

Constant torque (1000 h.p. approx. syn. speed) with direct-connected auxiliary motor.

Slip (s)	.05	.10	.20	.30
Energy returned at B′	47.5	90	160	210
Output of main motor and regulating machine	950	900	800	700
Input to main motor at A′	950	900	800	700
Net input to system at C′	950	900	800	700

Constant HP (1000) with motor-generator.

Slip (s)	.05	.10	.20	.30
Energy returned at B	52	112	250	430
Output of main motor	1000	1000	1000	1000
Input to main motor at A	1052	1112	1250	1430
Net input to system at C	1000	1000	1000	1000

Constant HP (1000) with direct-connected auxiliary motor.

Slip (s)	.05	.10	.20	.30
Energy returned at B′	50	100	200	300
Output of main motor and regulating machine	1000	1000	1000	1000
Input to main motor at A′	1000	1000	1000	1000
Net input to system at C′	1000	1000	1000	1000

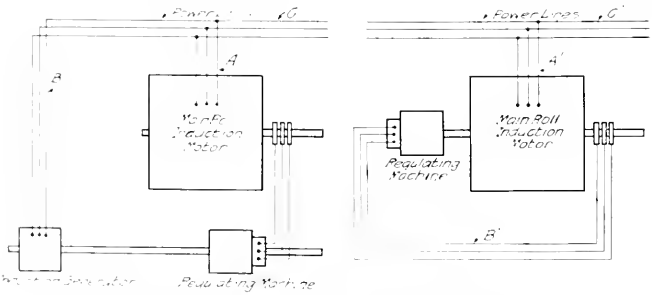


Fig. 10. Diagrams Indicating Flow of Power in Adjustable Speed Control System

Energy returned at B and B′ = Shaft horse power $\times \frac{s}{1-s}$

(constant torque) or is constant throughout the range. Obviously if the speed of the main roll motor is low the cost of the direct-connected auxiliary motor may be so high as to make it prohibitive, while if the speed is high a considerable gain in efficiency may be realized at little or no increase in cost. The effect of the nature of the load maintained throughout the speed range is shown by the tables and the diagrams in Fig. 10.

No attempt is made in these diagrams to show the electrical circuits other than those which indicate the flow of power.

In the preparation of these tables the losses due to the various transformations have been neglected in the interest of simplicity, as they do not affect the general principles which the writer is endeavoring to bring out. Also in the interest of simplicity it is assumed that the speed control is entirely below synchronism, the effect of double range control being discussed later.

In studying these tables the following fundamental principles must be borne in mind. Neglecting the internal losses, the power delivered to an induction motor running at any speed between standstill and synchronous speed is partly converted to mechanical energy at the shaft and partly transferred through the machine as electrical energy and appears at the slip rings. At standstill the motor acts exactly like a static transformer, no work being done at the armature shaft. At speeds up to synchronism the mechanical work done is proportional to the speeds and the electrical energy transferred through the slip rings is proportional to the slip.

It will be seen from these tables that the capacities of the main roll motors and of the equipments connected in the secondaries of

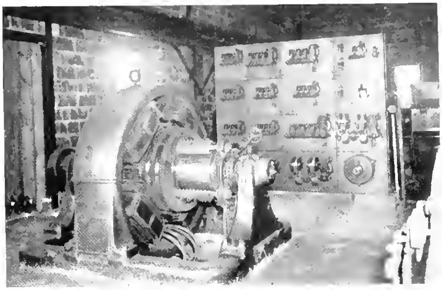


Fig. 8. Synchronous Converter Kraemer System

the roll motors, which are determined by the energies returned at B and B' and are less when the slip energies are converted to mechanical power than when returned to the supply systems as electrical energies. Practical considerations affecting the designs of the apparatus are such, however, as to reduce the cost differences below those suggested by the differences in capacities. Specially is this

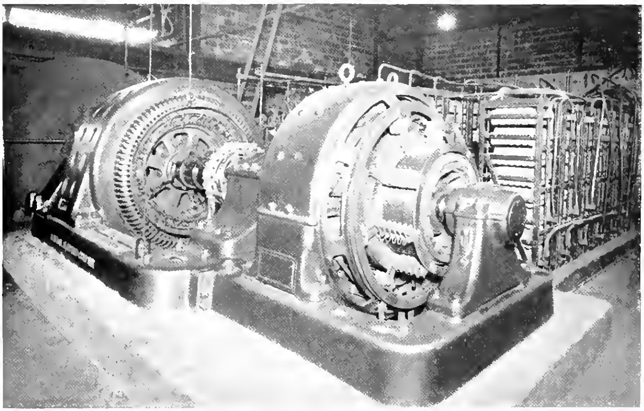


Fig. 9. Main Roll Drive Kraemer System Showing D-c. Motor Mounted on Main Roll Shaft with Induction Motor

true [illegible] system, all of which [illegible] are of the type in which [illegible] returned as electrical power. [illegible] the development of a com- [illegible] standard high speed regulating [illegible] can be applied to a wide range of [illegible] motors differing in capacities, speeds [illegible] speed ranges instead of requiring the development of a special auxiliary motor for nearly every main roll motor because of some difference in speed or capacity, or both.

On the other hand the Kraemer system has been developed along the other line, the slip energy being converted to mechanical power. The Kraemer system requires one additional machine over the corresponding Scherbius equipment and the effect of this unit on the price and efficiency are such as to make it imperative to adopt the drive with the smaller number of parts, and we find all but one of the installations of this system of the type having the regulating machine mounted on the main motor shaft. In developing the direct-current motors mounted on the main roll shafts for conserving the slip energy, recourse has been had to the very extensive development in direct-current generators for many of the expensive parts, which has materially reduced the costs of the expensive element of this system. Obviously the capacity of the regulating equipment in either system is determined by the amount of power transmitted through it, that is, by the capacity of the main roll motor and its range of control. However, in addition to this, its design is affected by the maximum rotor voltage and frequency.

The tendency of the synchronous converter to fall out of step at low frequencies makes the main roll motor with the Kraemer system unstable when carrying heavy overloads near synchronism. A rolling load with its rapid fluctuations over wide ranges aggravates this tendency towards instability. The addition of a flywheel, because it decreases the rates of change in the roll motor speeds and frequently reduces the slip, tends to stabilize the roll motors around synchronism. An example will serve to illustrate this. The curve in Fig. 11 shows the effect of weight of flywheel on the time torque curves of a 1200-h.p. motor driving a mill. This torque curve is typical of many of those to which adjustable speed motors are subjected and is less severe than one for a single stand mill in which the load is either all on or all off. The full line curve is that for the motor without flywheel having $WR^2 = 901,700$ lb. ft.^{2}. The dot dash curve corresponds to a flywheel effect of $WR^2 = 1,726,500$ lb. ft.^{2} and the dotted curve to a flywheel effect of $WR^2 = 4,500,000$ lb. ft.^{2}. Referring to the full line curve, the slip at point *A* is $6\frac{1}{2}$ per cent, which corresponds to a rotor frequency of 1.65 cycles. The slip at point *B* is approximately 11.6 per cent and the corresponding secondary frequency is 2.9 cycles.

A motor of this size with a normal range of speed control will require about a 300-kw., 25-cycle synchronous converter, which will run 750 r.p.m. at rated frequency. At 1.65 cycles it will run $49\frac{1}{2}$ r.p.m. and at 2.9 cycles, 87 r.p.m. or nearly double its former speed, and the time available for making this change in speed is 0.9 second. Obviously the change in speed of the synchronous converter increases with increasing fluctuations in load and will be a maximum for a single stand mill where the load varies from mill friction to rolling peaks.

If the synchronous converter is to successfully follow these rapid changes in speed as the load and speed of the main motor fluctuate, its synchronizing torque must be sufficient to overcome the inertia of its armature. This torque is a function of the impedance of the rotor circuit of the main motor including the armature of the synchronous converter and the line connecting them. At the normal frequencies at which synchronous converters are operated, 25 and 60 cycles, and even at the reduced frequencies met with in the Kraemer system when the main roll motor is operating considerably below synchronism, the reactance component of the impedance of the converter circuit predominates and the synchronizing torque, which is large, is very nearly constant for considerable changes in frequency and voltage.

But as the speed of the main motor approaches synchronism and the rotor frequency and voltage are correspondingly reduced we reach a point, depending upon the constants of the converter circuit, when the resistance becomes an important factor in reducing the synchronizing torque of the converter, and as the main motor approaches still further toward synchronism we reach a critical speed beyond which the synchronizing torque of the converter is not sufficient to drag its armature in synchronism with the fluctuations caused by the load on the main motor; the converter becomes unstable, falls out of step, and the main motor goes up to synchronism. Obviously the synchronizing torque required to keep the converter in step, and therefore the critical slip of the main motor, increases with the magnitude and rate of fluctuations in the load and vice versa; and as previously stated the addition of a heavy flywheel to the main motor will both reduce the slip and the rate of change in the main motor speed, and therefore that of the controlling converter, and improve the stability of the main motor by reducing the critical slip or raising the critical speed.

A physical conception of this phenomenon can be gained by assuming that the converter is controlled by the main motor through a rubber band and that as the main motor approaches synchronous speed the strength of the rubber band is decreased according to the law for the flow of current through a circuit containing reactance and resistance $\left(I=\frac{E}{\sqrt{X^2+R^2}}\right)$. The reactance at 25 cycles greatly overbalances the resistance, and the impressed voltage and frequency decrease as the main motor approaches synchronism, the resistance remaining constant independent of any changes in the main motor speeds.

Starting with the motor adjusted to run at minimum speed, and gradually increasing its speed, the strength of the band remains practically constant and the converter readily follows the speed changes in the main motor. As the speed of the main motor approaches synchronism the resistance becomes an important factor in the denominator and the rubber band decreases in strength rapidly until it is no longer capable of transmitting sufficient torque to the converter to drag it along with the main motor. The converter therefore eventually falls out of step. If however we then slow down the rate of change in the main motor by the use of a flywheel the force required to overcome the inertia of the converter armature decreases and the strength of the rubber band may be decreased still further by reducing the slip of the main motor and yet be sufficiently strong to drag the converter armature with it, until we arrive at a point where the strength of the band is just sufficient to overcome the friction of the converter armature. Beyond this point it is not possible to go without the converter falling out of step no matter how large a flywheel is used.

In the Scherbius system the changes in the regulating set which follow changes in the main motor are purely electrical, the set running at practically constant speed independent of any changes in the speed of the main motor, and the main motor is entirely free

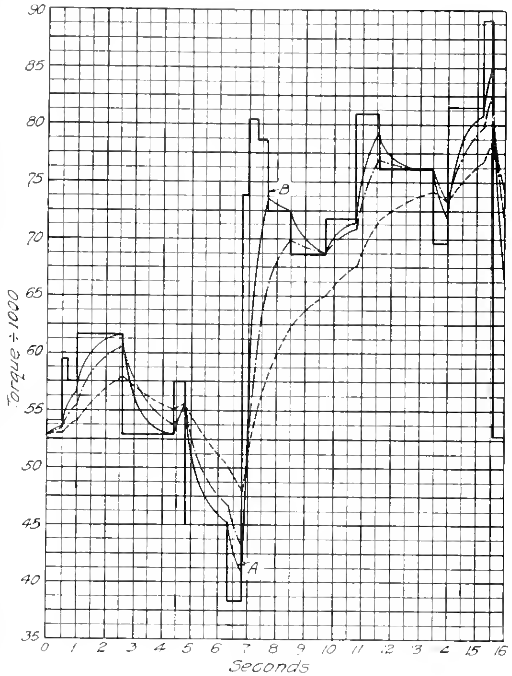


Fig. 11. Typical Rolling Mill Load Cycle

from instability at all loads up to its breakdown point near synchronous speed as well as at all other speeds.

This system, however, has its limitations. As the frequency and voltage are increased, it becomes more and more difficult to design the commutator motor of the regulating set to commutate properly under the severe rolling mill load. The practical commercial limit is reached at about 20 cycles, and as this is entirely too low to meet the requirements of mill motors if the control is all below synchronism operating on 60-cycle circuits, engineers devoted their attention to ways and means of reducing the frequency.

[illegible] motor can be controlled [illegible] below synchronism [illegible] given speed range [illegible] and approximately [illegible] speed of the main [illegible] range of speed con-

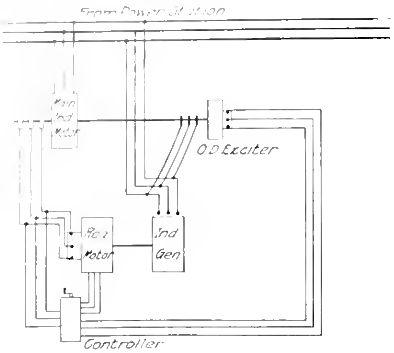


Fig. 12. Double Range Scherbius System

trol. In addition the capacity of the main motor will be lowered somewhat and that of the regulating equipment reduced to approximately half that required with single range control and the overall efficiency improved by the reduction in the losses.

That the Scherbius regulating equipment would function equally well above or below synchronism was appreciated from the beginning, but the problem of getting the main motor through synchronous speed remained unsolved on a practical basis until the advent of the well known double range Scherbius system which has been so extensively used since the development of the first equipment early in 1916 for the Bethlehem Steel Co. at their Saucon Works.

At synchronous speed the rotor current and voltage across the slip rings of an induction motor are zero and at this speed the roll motor can neither carry load nor provide excitation for the regulating set. If, however, we provide an auxiliary excitation for the regulating motor, which is automatically effective at and near synchronous speed and which does not interfere with the proper functioning of the regulating set at roll motor speeds remote from synchronism, we can drive the main motor up to synchronous speed where it will operate as a synchronous motor, and on through this speed to a point where the regulating set, without the assistance of the auxiliary exciter, will control the speed as it does below synchronism in the single range system. This is accomplished by means of the ohmic drop exciter driven from the main roll motor. When operating above synchronism the action of the regulating set is reversed, power being transferred by it to the main motor. However, this reversal of the flow of power has no effect on the functioning of the system. The elements of the double range system are shown diagrammatically in Fig. 12.

The number of poles and therefore the synchronous speed of the ohmic drop exciter are the same as for the main motor, and as its slip rings are connected to the general supply system it is apparent that the frequency of the current drawn from the commutator follows exactly the law governing the frequency of the current from the rotor of the roll motor and that the voltage at the commutator is approximately constant. At synchronous speed the ohmic drop exciter produces direct current. In appearance it resembles the armature of a synchronous converter, as is shown by Fig. 13.

The main roll motor does not differ from the standard induction motor for this service except for the addition of the ohmic drop exciter which, as previously stated, provides excitation for the regulating motor when carrying the roll motor through synchronous speed (see Fig. 14).

The starting and regulation of a motor equipped with double range Scherbius control


Fig. 13. O. D. (Ohmic Drop) Exciter

is very simple. Two controllers are needed, one for starting and one for speed control. With the speed controller set at the position corresponding to synchronous operation for the roll motor and the starting controller in the off position, the regulating set is started through the induction generator by a compensator in the ordinary way for induction motor-generators. Then the main motor is started in the usual way and when the starting resistance is all cut out the armature of the regulating motor is connected to the slip rings and its field circuit closed automatically through an interlock on the last contactor of the starting control for the main roll motor. The speed of the rolls is then adjusted to any desired value by the regulating controller.

With this system it is possible to meet the most exacting rolling speed requirements without exceeding the limiting frequency for the regulating set and to carry the maximum overloads at all speeds from minimum speed through synchronism to maximum speed. In fact, without instruments in the rotor circuit an observer cannot tell when the motor passes the synchronous speed. A very interesting experiment which is frequently tried with this equipment to illustrate this feature is: With the motor running slightly loaded just above synchronism, to increase the load gradually and watch the rotor frequency approach zero and then the phase rotation of the rotor voltage reverse and the frequency increase as the machine passes below synchronism.

With the Kraemer system the main motor may be forced through synchronism at comparatively light load and then controlled above as it was below; but the gap in the speed range caused by the instability of the roll motor when loaded near synchronous speed, both above and below, and the difficulty of forcing it through synchronism make this system impracticable for double range operation. This gap is obviously much greater with 25-cycle than 60-cycle equipment.

In addition to reduced first cost and generally higher efficiency over the whole range of control, the double range Scherbius system provides a maximum efficiency about midway in the speed range, which is usually the zone in which the greater part of the mill output is rolled. The system is also quite flexible in this respect, and the synchronous speed may frequently be arranged at other points if production warrants it.

It is occasionally found desirable to increase the speed of a mill over that originally contemplated, and this can readily be done with almost no interruption in production by substituting a larger regulating set in the double range system, while usually this will require a much more expensive change in the main roll motor which may delay the mill several weeks for either the Kraemer system or the single range Scherbius system.

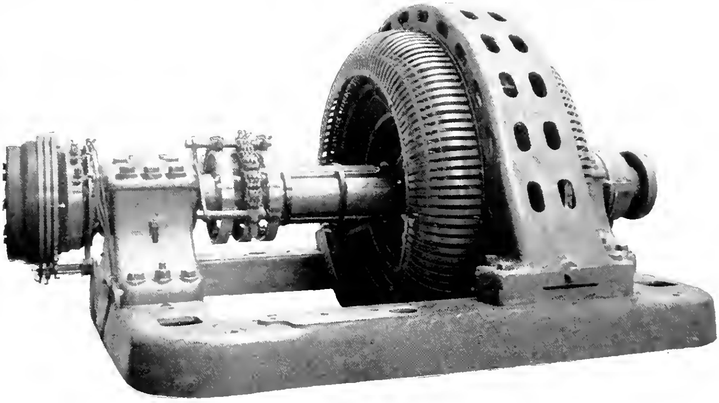


Fig. 14. Main Roll Motor with O. D. Exciter

Efficiency

It is difficult to discuss relative efficiencies of the different systems in a general way because of the effect of changes in assumption upon the characteristics of each system and therefore the values which follow must not be applied except when the conditions are approximately normal. As a basis upon which to make a comparison a moderate speed motor of approximately 1000-h.p. capacity and 40 per cent speed control has been assumed. For such an equipment the [illegible] will be approx- [illegible] [m]aximum speed, $82\frac{1}{2}$ [illegible] [sp]eed for the direct- [illegible] [m]otor field control and [illegible] [g]enerator, and $87\frac{1}{2}$ at [illegible] and 87 per cent at minimum

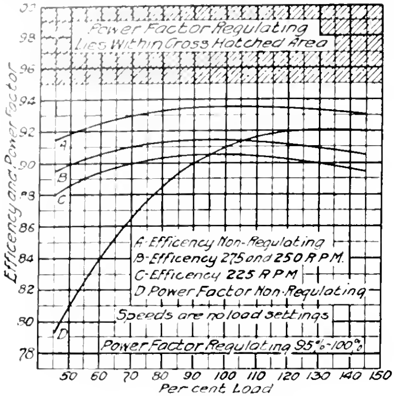


Fig. 15. Typical Efficiency and Power-factor Curves for Adjustable Speed Induction Motor with Double Range Scherbius Control

speed if a synchronous converter is substituted for the motor-generator.

Assuming the load conditions to be those most favorable to each system, that is, constant horse power for the Kraemer system and constant torque for the Scherbius system, the efficiencies are approximately the same for each, and for an equipment of the capacity and speed range assumed above will be approximately 91 per cent at maximum speed and 89 at minimum speed. The Scherbius system is less affected by changes in load conditions and its efficiency will therefore usually be higher under normal conditions, that is, where the load varies between constant horse power and constant torque over the range of control.

All three of the systems may be designed for high power-factor, the cost of doing this being independent of the speed of the roll motor if the rolls are driven by an adjustable speed direct-current motor, but will increase for lower speeds of the roll motor with either the Kraemer or Scherbius systems. Fig. 15 shows a set of typical efficiency and power-factor curves for the double range Scherbius system. Attention is called to the following points:

1st. The high efficiency half load to approximately 50 per cent overload (curves A, B, C).

2nd. The increase in power-factor when running regulating at all speeds as compared with the power-factor running non-regulating at nominal full speed load (curve D).

Factors to be Considered in Making a Choice

The choice of the system of control to meet any specific mill requirements can be made only after careful consideration of all the conditions affecting the problem.

However, the more general conditions having a bearing on the choice are: Range of speed control, frequency of supply circuit, maximum load at all speeds, production of mill at different speeds, and whether the control is to be automatic.

The double range Scherbius system can readily be designed to meet all except the most extreme speed ranges for both 25-cycle and 60-cycle supply circuits; while the Kraemer system is rather handicapped if the supply frequency is 25 cycles.

When automatic control is required the direct-current systems with motor-generator will usually give better results.

There are, however, a number of important advantages in favor of the double range Scherbius system which must be considered in making a choice. They are:

Generally higher efficiency and correspondingly lower power consumption throughout the entire range of control.

Frequently a considerable part of the output of a mill may be rolled by the motor without the regulating set, due to the motor speed falling intermediate between the upper and lower limits of the range. This is a very great advantage over any single range system, since in event of the failure of the regulating set the high speed at which the roll motor with single range control runs non-regulating limits the production of the mill to small sections while the regulating equipment is being repaired.

It is free from instability at any speed and will carry its high overloads at all speeds throughout the range.

Its cost is usually lower than that for the other systems when compared on the same basis, i.e., range of speed control over which the maximum roll motor loads may be carried without the roll motor becoming unstable.

In common with the other systems a large number of speed points may be provided, the power-factor of the main motor may be raised, and the equipment is thoroughly reliable and readily maintained by the operating department.

Export Coal Facilities at the Curtis Bay, Md., Terminals of the Baltimore & Ohio Railroad

By P. G. Lang, Jr

Assistant Engineer of Bridges, Baltimore & Ohio R.R. Co.

In the January issue of the General Electric Review there appeared in the article, "Some Developments in the Electrical Industry During 1920," a brief description of the electrically operated coal trimmers installed at the coal loading pier of the Baltimore & Ohio Railroad Company, Curtis Bay, Md. The author in the following article describes in detail the facilities for handling coal at this point which during recent years have undergone material and expensive improvements. The entire work of developing, detailing and installing the machinery, including its initiation into service, was performed under the author's personal and direct supervision.—Editor.

Export coal at the Curtis Bay Terminals of the Baltimore & Ohio Railroad Company is handled over a modern pier carefully designed for the purpose and completed early in 1917. The coal is deposited by two special car dumpers upon four main 60-inch conveyor belts by means of which it is moved longitudinally of the pier and discharged upon four transverse shuttle belts supported by movable loading towers, whence it is conveyed within the holds of steamers moored beside the pier. The mechanism of the loading towers is so designed as to permit the free movement of the transverse belts longitudinally, transversely and vertically with respect to the pier, in order that the coal discharge may be adjusted to suit the varying beams, drafts and hatch arrangements of the vessels presented for loading.

This pier, when completed in 1917, represented the highest contemporary attainment of science as applied to the bulk transfer problem, and, during the first two years of its existence and use, demonstrated a capacity which fully justified the expectations of those responsible for its construction. In one instance, there was in one hour and 58 minutes transferred over this pier and deposited within the hold of a vessel, 7222 tons of bituminous coal, and this is believed to be a rate never previously attained in bulk transfer.

Continued experience in the operation of the Curtis Bay facilities confirmed the feasibility of this type of pier as a transfer medium, and brought into prominence another phase of the general problem—that is, the distribution or "trimming" of coal after it had been deposited within the holds of vessels.

During 1917 and 1918 coal trimming was performed at Curtis Bay by hand labor and large numbers of laborers were engaged in the work. Hand trimming, under the most favorable conditions, cannot keep pace with mechanical delivery, and this fact was the cause of frequent and expensive delays in the operation of the pier, which was during loading periods compelled at frequent intervals to suspend its operations in order to afford the trimmers an opportunity to distribute the coal properly within the cargo space. These conditions occurred during the

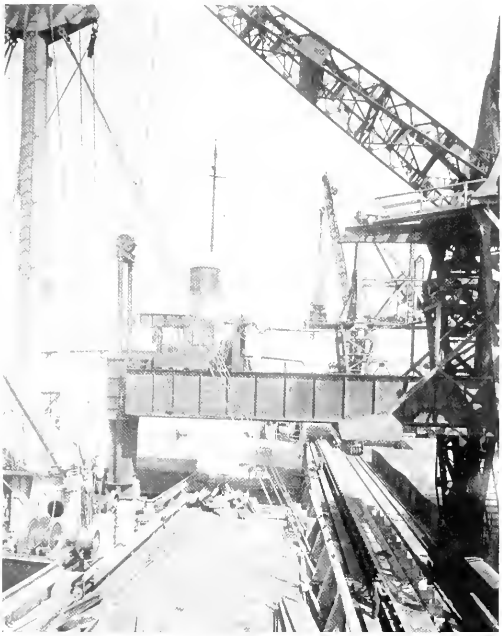


Fig. 1. Conveyor Tower and Ram with Coal Trimmer in Position to Operate

[illegible] ...ated by the [illegible] ...ment management [illegible] ...coal trimming [illegible] ...conditions at the [illegible] ...arefully studied [illegible] ...a mechanical [illegible] ...ce of the trimming [illegible] ...was placed in the [illegible] Mr. H. A. Lane, Chief [illegible] Baltimore & Ohio Railroad [illegible] power Board.

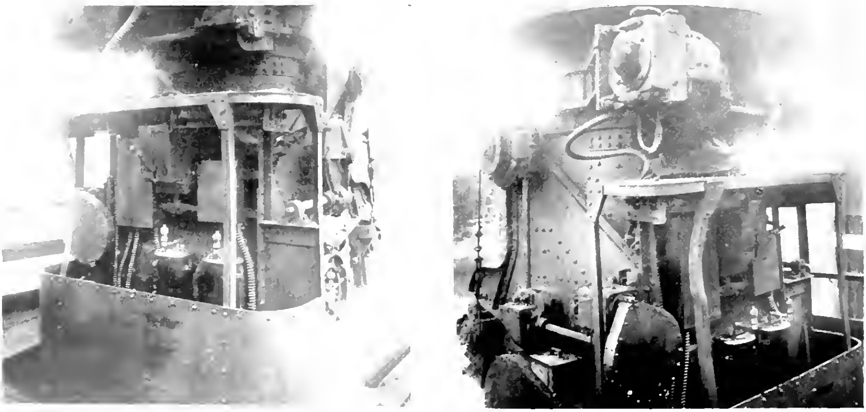
The [illegible] trimmer was placed in operation [illegible] December 27, 1919, and its initial performance was the distribution of 1000 [illegible] petroleum coke in the S. S. *Victorious*. At this time the practicability of the machine [illegible] fully established; the performance however was strictly experimental and later numerous minor adjustments and changes were made in the machine. Although such changes and adjustments are spoken of as "minor," they were vitally essential to the successful and continuous operation of the mechanical trimmers. The last, or fourth, machine was placed in service on April 9, 1920. A brief description which applies to all four machines follows:

The trimmers are supported from the end of the conveyor tower by large booms. An operator at the end of the ram in the conveyor tower controls the placing of the trimmer into the boat (Fig. 1). This is done through the magnetic control of two 75-h.p. motors; one motor hoists and lowers the trimmer, the other motor raises and lowers the boom.

Fig. 2. Coal Trimmer at Bottom of Telescope Chute. Collecto Rings (with Cover Removed) Just Above the Operator's Cab

This last motion has the effect of moving the trimmer laterally to the ship. This same operator can also move the tower along the dock and this carries the trimmer longitudinally to the ship.

The operator in the trimmer (Fig. 2) controls the speed of the belt conveyor in the



Figs. 3 and 4 Detail Views of the Trimmer Operating Cab and Equipment trimmer, and can rotate the trimmer so as to throw coal into any desired corner of the cargo hold. Also he can raise and lower the end of the belt conveyor so as to control the height to which coal is thrown. The belt conveyor is driven by a nominally rated 50-h.p., shunt wound, open type motor which is totally enclosed in a sheet metal box. The rotation is obtained by a small series wound enclosed motor controlled by a drum controller. The elevation of the trimmer belt is controlled by a third series wound enclosed motor. In the operator's cab all electrical controllers are of the drum enclosed type (Figs. 3 and 4) and the power can be taken off the trimmer by an enclosed cutout switch. Power is furnished by 550-volt direct current which comes to the trimmer from the main conveyor tower, first, through a long flexible cable which is held to the proper length by an automatic cable-reel take-up; second, the power passes down the leg of the trimmer chute; third, passes through enclosed collector rings (shown open in Fig. 2) to the main protective switch in the operator's cab.

Since April 20, 1920, the service performance of the coal trimmers has exceeded expectations, and has been productive of vast economies of time and money in connection with the cargoing of vessels at the Curtis Bay Terminals.

While it is felt that a practicable solution has been evolved for the vexatious conditions which previously existed at Curtis Bay, the trimmers are still a subject for experiment. One important element in connection with mechanical trimming by this method is the conveying belt, which forms an essential part of the device, and by means of which the throwing of the coal is accomplished. Experiments have been conducted to determine the variety of belting most suitable to this service, and these have not yet been finally concluded.

The soundness of the principles involved in the design of the machines has been amply demonstrated by their satisfactory performance under the severe service conditions which they were forced to meet at Curtis Bay, including not only the trimming of coal, which descends upon the conveyor belt in all sizes up to a maximum lump of about 200 lb. weight, but also the passage of foreign objects, which sometimes find their way into the chute and make their exit over the trimmer belt. Numerous articles of this nature, including fragments of steel ranging in length to eight feet, huge stones weighing 500 to 600 lb., car springs and other objects, have made the passage and been thrown from the machine without damage to the trimmer.

The device described is known by the trade name of the Lane-Galloway Trimmer, and patents are now pending. The machine is absolutely new and original in character, and represents, so far as we have been able to learn, the most economical and practical solution of this very important phase of the bulk transfer problem.

Fig. 5. General View Showing a Vessel with Two Mechanical Trimmers in Operation

Methods for the Production and Measurement of High Vacua

PART VIII. PHYSICAL CHEMICAL METHODS (Continued)

By Saul Dushman

Research Laboratory, General Electric Company

[illegible] certain purely chemical methods of removing residual gases and also electri- [illegible] at moderately low pressures. The next installment will deal with electrical clean-up [illegible] devices and lamps, and also with the phenomena of gas ionization.—Editor.

CHEMICAL METHODS FOR THE CLEAN-UP OF RESIDUAL GASES

As has been mentioned in the previous sections, it is often extremely difficult to draw any distinct line of demarkation between so-called purely physical and purely chemical reactions when dealing with clean-up processes at low pressures. In the general discussion of sorption phenomena it has been necessary to refer to reactions which are undoubtedly chemical inasmuch as definite compounds are formed. Thus, when hydrogen is taken up by the alkali metals, we have every evidence that a chemical compound, a hydride, is formed. On the other hand, it is still a debatable question as to whether a hydride is formed in the reaction between hydrogen and palladium.

In the following section we shall discuss a type of clean-up reaction in which the gas disappears because of a reaction with a heated solid. The resulting compounds are volatile at the temperature of the reaction and condense on colder parts of the system, thus making it possible for the clean-up to continue as long as residual gas is present. On the other hand, since the rate of clean-up decreases ordinarily with the pressure, a point is reached at which the rate of disappearance of gas is equal to the rate of evolution from walls and other parts of the system.

Clean-up of Gases by Calcium

The use of this method for the production of high vacua was first proposed by F. Soddy.[1] He found that in a gas at reasonably low pressure, the heating of calcium to a temperature at which it begins to volatilize would cause the pressure to decrease rapidly to a point at which the gas is "non-conducting." For heating the calcium, Soddy recommends either a small quartz-tube furnace wound with platinum wire, or an inductive method of heating (analogous to that used in the most recent types of high-frequency furnaces devised by Northrup). No data are given by Soddy as to the degree of vacuum actually attained or to the rate of clean-up. As an indicator of the degree of vacuum, he used a spectrum tube and describes his results as follows:

"If the apparatus (consisting of a large vessel in which is contained the quartz-tube furnace), charged with a small piece of calcium, and furnished with a Plucker spectrum tube, is exhausted by a Fleuss pump and the furnace heated, gases consisting of compounds of hydrogen, carbon, and oxygen are given out by the calcium. If the connection with the pump is then shut off and the heating continued, absorption of the remaining gases accompanied by volatilization of the calcium takes place, and the vacuum rises almost instantly to a point at which no discharge can be passed through the spectrum tube. By a non-conducting vacuum is to be understood one of greater resistance than an alternative spark-gap in air of 2 to 3 cm."

Soddy observes that CO, CO_2, H_2O, C_2N_2, SO_2, NH_3, and oxides of nitrogen are all readily cleaned up. In the case of hydrogen the absorption is not so great. "There is no doubt," Soddy states, "that a low initial pressure, not exceeding a few millimeters of mercury, is as essential a condition in causing calcium to combine with gases as a high temperature. For rapid and continuous absorption, volatilization is essential. The film of volatilized metal continues, even in the cold, to absorb, although more slowly than the vapor itself."

Argon, helium and the other rare gases are, of course, not cleaned up by calcium, so that this method has proved useful for the purification of the rare gases. Mr. J. H. Clough, of this laboratory, has found[2] that for this purpose the best results are obtained by means of a discharge tube containing a solid calcium anode and robust tungsten filament as

[1] Proc. Roy. Soc. Lond. A 78, 429 (1907).
[2] Patent Specification No. 1,246,654 (1917).

cathode. The two electrodes are placed fairly close to each other, and on lighting the filament it is possible to start an arc in the rare gases at very low voltages. Under the action of the arc, the calcium at the anode is gradually volatilized and the chemically active gases are absorbed.

Clough has also observed that titanium and magnesium are very effective as clean-up metals when used in the above manner. There is some evidence according to Mr. G. M. J. Mackay[3] that the reaction here is not altogether a straight chemical one. "Apparently the arc activates the gaseous impurities so that they combine more readily with the chemical agents (calcium, etc.) in the bulb."

In order to obtain some data on the practical value of the calcium reaction in cleaning up residual gases, Mr. C. A. Kidner carried out, at the writer's suggestion, some experiments with hydrogen. This gas was chosen because it is the most difficult to clean up, and also because it is the most frequent constituent of residual gases present in high vacuum devices.

Calcium in the form of wire was laid inside a tungsten spiral, so that it could be heated by passing current through the latter. By varying the filament current, the rate of volatilization could be varied and the rate of clean-up measured under different conditions. The pressure was measured by a McLeod gauge, and the volume of the system containing hydrogen was 2500 cm^3. In one experiment, the pressure was decreased from 250 to 4 bars (approximately) in almost 30 minutes. At the end of this interval the calcium had been practically all volatilized and covered the sides of the bulb. It was observed that the rate of clean-up increases with the temperature of the calcium and is apparently proportional to the pressure of hydrogen.

Similar experiments were tried with magnesium, but no noticeable clean-up was observed. Soddy found that strontium and barium act similarly to calcium, but as the latter can now be obtained commercially in very pure form it is much more convenient for use. Soddy also observed that the presence of CaH_2 in the calcium makes the metal much more difficult to volatilize.

Measurements by Mr. Kidner at higher pressures (10 to 100 bars) showed that the calcium deposit on the glass does not adsorb either hydrogen or oxygen to any marked extent. Even active hydrogen (formed by heating a tungsten filament to a high temperature in the hydrogen) is only slightly adsorbed by the cold calcium deposit. On the other hand, in some earlier experiments carried out by the writer, in which an ionization gauge was used, it was observed that with a low initial pressure of hydrogen the calcium deposit does clean-up the gas gradually. Thus, in one case, the pressure in a sealed off system of about 500 cm^3 capacity decreased from 2 to 0.7 bars during the volatilization of the calcium (which occurred in a few minutes), and subsequently the deposit continued to adsorb gas until at the end of two hours the pressure had decreased to about 0.0007 bars.

These observations, along with Soddy's results, lead to the conclusion that, in order to clean-up large amounts of gas with calcium, it is necessary to heat the metal to a high enough temperature to cause fairly rapid volatilization. On the other hand, with calcium volatilized in a low pressure of gas so that the deposited metal is presumably not saturated with gas, the cold deposit gradually adsorbs the small amount of residual gas and it is thus possible to obtain a fairly low pressure. In using calcium to clean-up small traces of residual gas, it is naturally advisable to heat the metal for a short interval of time while the system is still connected to the exhaust pump, to get rid of occluded gases.

Clean-up of Residual Gases by Incandescent Tungsten Filaments

In a series of investigations on the reactions between different gases and heated tungsten filaments, Dr. I. Langmuir observed that under certain conditions a chemical clean-up of the gas occurs.[4] The principal gases studied were oxygen, nitrogen, hydrogen, carbon monoxide and dioxide, chlorine, bromine and iodine, methane, cyanogen, hydrochloric acid, argon, phosphine, and the vapors of many substances, such as mercury, phosphorus pentoxide, sulphur, etc. While the discussion of the theoretical aspects of these investigations must be reserved for a subsequent section, we shall mention briefly, in the present connection, the conditions under which the best clean-up results can be obtained with different gases.

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[3] Patent Specification, No. 1,208,597 (1917).

[4] Dr. Langmuir has reviewed the results of these investigations up to 1915 in a paper on "Chemical Reactions at Low Pressures," J. Am. Chem. Soc. *37*, 1139 (1915); also see J. Industrial and Eng. Chem., *1*, 348 (1915).

[illegible] *[illegible] ungsten Fila-* [illegible]

[illegible] 200 deg. K., and [illegible] 100 bars, the oxide [illegible] is formed, leaving [illegible] The rate of [illegible] at constant filament [illegible] ortional to the pressure [illegible] is, the reaction is of the [illegible] denotes the original pressure [illegible] at any interval of time t, [illegible] the experiment, is given [illegible]

$$V\frac{dp}{dt} = k\,p.A$$

or

$$p = p_0\,\epsilon^{-kAt/V} \qquad (1)$$

where [illegible] is a *constant* whose value depends on the temperature of the filament, V denotes the volume of the system, and A the area of the filament. Furthermore as k increases exponentially with the temperature, it follows that to obtain a rapid clean-up the temperature of the filament should be made as high as practicable (ordinarily about 2500 to 2700 deg. K.).

In a typical experiment in which the volume of the system used was 1075 cm³, and the initial pressure 9.41 bars (7.06×10^{-3} mm. of mercury), a tungsten filament 5.4 cm. long and 0.0394 mm. diameter was heated to 1470 deg. K., and it was observed that the pressure decreased to one per cent of its initial value in 23.5 minutes. The initial amount of oxygen, *measured at 298 deg. K. and atmospheric pressure* was 10 cubic mm. Fig. 66 shows the quantity of oxygen present at any instant plotted (on semi-logarithmic paper) as ordinate against the time in minutes. From the form of equation (1) it is evident that, for equal intervals of time, the pressure must decrease in the same ratio, so that plotted on semi-logarithmic paper the resulting graph is a straight line. From this curve and the measurements on the variation in k with temperature, the graphs for a number of other temperatures have been calculated and drawn in. The table which follows gives the value of the interval of time that would be required to reduce the total quantity of oxygen to 0.1 per cent of its original value if the tungsten filament described were heated to different temperatures.

T (Degrees Absolute)	t (minutes)
1470	34.5
1570	19.5
1770	7.2
2020	3.7
2290	1.93
2520	1.52
2770	1.22

At pressures below about 0.001 bar there is evidence that oxygen does not perceptibly attack a tungsten filament, so that this would appear to be about the lower limit of pressure attainable with this method.

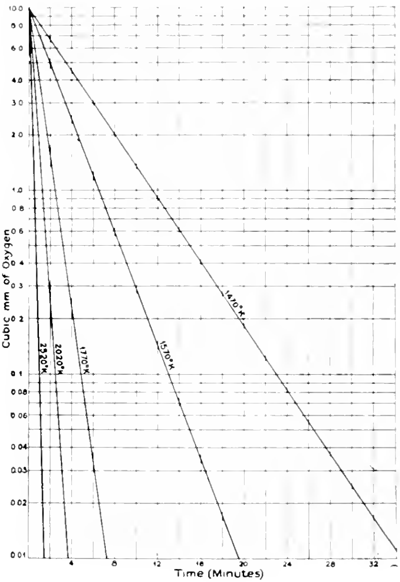

Fig. 66

(2) *Clean-up of Nitrogen by a Tungsten Filament*[6]

At pressures below about 100 bars, the rate of clean-up of nitrogen by a tungsten filament maintained at constant temperature is observed to be *constant* down to pressures as low as about two or three bars. It has been shown by Langmuir that the clean-up is due to combination between tungsten atoms evaporated from the filament and nitrogen molecules to form WN_2. Hence, in the foregoing range of pressures, the rate of clean-up is governed exclusively by the rate of evaporation of tungsten and increases with the latter. Fig. 67, taken from Langmuir's paper, gives the rate of clean-up in cubic mm. of nitrogen (measured at 298 deg. K. and atmospheric pressure) per minute per sq. cm. of tungsten filament, as a function of the temperature. "At lower pressures the rate is no longer constant because the nitrogen molecules become so scarce that a large fraction of the tungsten atoms strike the bulb without colliding with nitrogen molecules." However, on cooling the bulb containing the filament in liquid air, the tungsten atoms are found to combine with the nitrogen molecules adsorbed on the glass, and the rate of clean-up is materially increased. As will be described more fully below, this observation has been applied by Langmuir in obtaining extremely high vacua.

(3) *Clean-up of Carbon Monoxide by a Tungsten Filament*[7]

"With the bulb at room temperature, carbon monoxide was observed to behave exactly like nitrogen. In fact, with the filament at a given temperature, the curves obtained first with nitrogen and then with carbon monoxide proved to be identical. This proved that each atom of tungsten combined with one molecule of CO, presumably to form a compound WCO." But with the bulb immersed in liquid air, the rate of clean-up was observed to be very much greater, but still linear, as in the case of nitrogen and CO at ordinary temperatures of the bulb.

(4) *Clean-up of Hydrogen by a Tungsten Filament*[8]

When a tungsten wire is heated to a temperature above 1300 deg. K. in hydrogen at low pressure (1 to 20 bars), a portion of the gas is dissociated into atomic hydrogen and this is readily adsorbed by glass surfaces at room temperatures and much more at liquid air temperatures. It is possible in this manner to clean-up 20 to 50 cubic mm. of hydrogen.[9] A limit to this clean-up is however set by the fact that the "hydrogen atoms react to form molecular hydrogen as soon as they come in contact, even at liquid air temperatures." The amount of hydrogen gas that can be cleaned up in this manner by a heated tungsten filament is very variable and fatigue effects are apt to be observed, so that this method cannot be recommended as very useful in cleaning up residual amounts of hydrogen gas.

Traces of oxides present in a bulb are reduced by the active hydrogen with formation of H_2O. The latter is then dissociated again at the filament forming WO_3 which distills to the bulb and active hydrogen, which again reacts with the WO_3 on the bulb to form tungsten and H_2O. The result is that the glass walls become covered very rapidly with

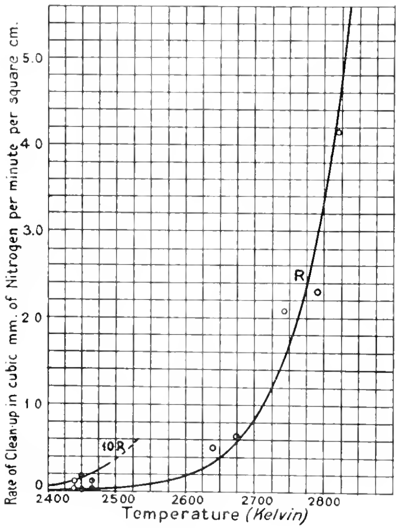

Fig. 67

a black deposit, due to the disintegration of the filament. This is also the reason that even slight traces of water vapor in the presence of a heated tungsten filament will produce an apparently continuous evolution of gas.[10]

(5) *Vacuum Attainable by Heating a Tungsten Filament in Contact with Residual Gases*

The observation that a tungsten filament heated to a very high temperature causes the clean-up of practically every gas to a very low pressure was utilized by Langmuir in the

[7] J. Am. Chem. Soc. *37*, 1159 (1915).
[8] See references in J. Am. Chem. Soc. *37*, 1161 (1915).
[9] Trans. A.I.E.E., *32*, 1913 (1913).
[10] This effect has been described by Langmuir in the paper in Trans. A.I.E.E., *32*, 1913 (1913).

produ[illegible] high vacua that are [illegible] accurate data on the [illegible] metals.[11] The method [illegible] bulb into which the [illegible] also contains an auxil[illegible] filament. After evacuating and [illegible] metal parts to a high tempera[illegible] on the pump, the bulb is sealed [illegible], immersed in liquid air, and the auxiliary [illegible] heated to 2800 to 2900 deg. K.[12] The residual gases are cleaned up to a very low pressure and if the bulb is kept immersed in liquid air while making the electrical measurements, this high vacuum is maintained.

Some experiments made at the writer's suggestion by Messrs. H. Huthsteiner and C. A. Kidner to determine the degree of vacuum attainable by this method yielded interesting results. Using a hairpin filament about 0.0076 cm. diameter and 7.5 cm. long, with heavy nickel leads (0.1 cm. diameter) to prevent excessive heating of the latter, it was possible by heating the filament to 2700 deg. K. to obtain a clean-up from about 0.02 bar to 0.0015 bar, the pressure being measured by an ionization gauge attached to the bulb. An appendix sealed onto the system, consisting of the gauge and bulb, was then immersed in liquid air and on heating the filament to 2700 deg. K. the pressure was observed to decrease to 0.001 bar.

In another experiment in which the bulb containing the tungsten filament was wholly immersed in liquid air during evaporation of the tungsten, the pressure was decreased from about 0.1 bar to 0.0005 bar. Taking into account the fact that during these experiments the ionization gauge itself was not immersed in liquid air, there is no doubt that the degree of vacuum attainable in Langmuir's experiments must have been better than 0.0005 bar, and probably nearer 0.0001 bar.

In some more recent experiments, Huthsteiner has observed that a small trace of P_2O_5, sublimed into the bulb before sealing it off the pump, materially assists, in the presence of the heated filament, in cleaning up residual gases to a very low pressure. This is evidently due to the fact, previously observed by Mr. G. M. J. Mackay,[13] that P_2O_5 is capable of cleaning up very large amounts of atomic hydrogen. Also the well-known hygroscopic properties of P_2O_5 make it a very efficient reagent for absorbing residual water-vapor. The only disadvantage of this substance is its comparatively high vapor pressure even at ordinary temperature. It has, however, been observed in this laboratory that fused P_2O_5 has a lower vapor pressure.

Some experiments carried out a number of years ago by Mackay and Huthsteiner yielded interesting results on the quantities of hydrogen and nitrogen that can be cleaned up by P_2O_5 in the presence of a heated tungsten filament. By heating the filament to 2300 deg. K., the pressure in a volume of 850 cm^3 could be reduced from 150×10^{-3} mm. to 1×10^{-3} mm. of mercury in two minutes. With the filament at 2700 deg. K., the pressure was reduced from 1.005 mm. to 4×10^{-3} mm. in about three minutes. That the clean-up is due to P_2O_5 vapor was shown by cooling the bulb to the temperature of liquid air, when there was observed only a slight disappearance of hydrogen.

ELECTRICAL CLEAN-UP OF GASES AT HIGHER PRESSURES

The gradual clean-up of gas during the passage of an electrical discharge in a "vacuum" tube was first observed by Plücker in 1858. As the gas disappears, the voltage required to pass current through the tube increases and, finally, the vacuum becomes "non-conducting." In the gas-filled X-ray tube, this phenomenon was known as "hardening," since the higher the voltage required to produce the discharge, the "harder" the resultant X-rays became.[14] In spite of the large number of investigations on this subject, the exact cause of the phenomenon is as yet an open question. "The effect is undoubtedly not a simple one, and there are probably several contributory causes." S. Brodetsky and B. Hodgson[15] have given the following list of the explanations which have been proposed:

(1) Chemical action between the gas and the glass[16]

(2) Chemical action between the gas and the cathode[17]

(3) Chemical or mechanical action between the gas and the anode[18, 19, 20]

[11] Zeits. f. Elektrochem., *15*, 516 (1914).

[12] For method of determining the temperature of tungsten filaments, see I. Langmuir, GENERAL ELECTRIC REVIEW, *19*, 208 (1916).

[13] See Patent Specification No. 1,249,978 (1917), and also No. 1,208,597 (1917).

[14] See, for instance, G. W. C. Kaye, "X-Rays," which gives in Chapt. VI a discussion of this effect as observed in the older type of X-ray tubes.

[15] Phil. Mag. *31*, 478 (1916).

[16] R. S. Willows, Phil. Mag. *6*, 503 (1901).

[17] Mey, Ann. d. Phys., *11*, 127 (1903).

[18] C. A. Skinner, Phil. Mag. *12*, 481 (1906).

[19] B. Hodgson, Phys. Zeit., *13*, 595 (1912).

[20] L. V. Chr[illegible], Phys. Zeit., *10*, 745 (1909), Phys. Rev. 29, [illegible].

(4) Chemical action due to active nitrogen[21]

(5) Mechanical occlusion of the gas in the glass[22]

(6) Mechanical occlusion of the gas in the cathode[23]

(7) Mechanical occlusion of the gas in the disintegrated part of the cathode[24]

It is well to remember in this connection that, according to our present views, electric conduction in gases is effected by means of electrons and positive ions, the latter being produced either by bombardment of the anode by electrons or by collision of the latter with gas molecules. The positive ions attain, under even moderate voltages, velocities which are much greater than those possessed by ordinary gas molecules in virtue of their kinetic energy of translational velocity. Thus, at ordinary temperature, the mean velocity of a molecule of hydrogen is about 1900 meters per second, and that of a molecule of nitrogen about 500 meters per second. When these molecules are ionized, the velocity is given by the relation

$$\frac{1}{2} mu^2 = V\epsilon$$

where m = mass of the ion

u = velocity of the ion

V = potential difference through which the ion passes

ϵ = charge on an electron (or ion with unit positive charge).

Converting to ordinary units, this relation becomes

$$u = 1.396 \times 10^6 \sqrt{V/M}\ cm.\ sec^{-1}.$$

where V is expressed in volts and M is the molecular weight of the gas. So that at 100 volts, the velocity of a hydrogen ion would be 9800 meters per second, and that of a nitrogen ion 2600 meters per second. At higher voltages, the velocities would be still greater. It is therefore reasonable to expect that such high velocity molecules might be able to penetrate into the glass walls in much the same manner as the alpha particles (positively charged helium atoms) expelled by radioactive atoms. On the other hand, if we compare the energy of high velocity ions with the kinetic energy of molecules at higher temperatures, we find that a hydrogen ion moving through a field of 100 volts has the same kinetic energy as a hydrogen molecule at about 7500 to 8000 deg. K. It would therefore not surprise us to find that such ions are capable of combining chemically with molecules upon which they happen to impinge.

According to Langmuir[25] both these types of reactions occur in the clean-up of nitrogen in presence of a hot tungsten cathode when an electric discharge passes. At higher pressures, the reaction is "electro-chemical," the nitrogen combining with the tungsten to form the nitride WN_2. At very low pressures and high anode voltages, the action is apparently purely mechanical (Langmuir designates this the "electrical" clean-up). The nitrogen is driven into the glass in such a form that it can be recovered by heating. The action is thus apparently reversible, and only limited quantities of nitrogen can be cleaned up in this manner. The electric clean-up, as distinguished from the electro-chemical, also exhibits distinct fatigue effects.

It is quite probable that both these two types of clean-up occur simultaneously in practically all the cases where gases disappear during electrical discharge, and we shall find that this point of view enables us to interpret to a large extent the many apparently contradictory results obtained by the different investigators.

Willows[16] observed that the amount of clean-up of gas in a discharge tube varied according to the nature of the glass from which the tube was made. The adsorption was least in Jena glass, more in lead glass, and greatest in soda glass. At constant current, the absorption was found to increase with decrease in pressure. The conclusion arrived at was that the clean-up is due to chemical reactions between the gases and the glass walls. In support of this view, S. E. Hills[21] has shown that absorption is observed with air in an electrodeless discharge. His experiments were carried out in the range of pressures varying from 0.4 mm. to 0.04 mm. of mercury. During these experiments the bulbs became covered with a dark deposit on the walls, presumably due to oxidation reactions. On exhausting these bulbs and filling them with hydrogen at about one mm. pressure, the discharge caused a rapid disappearance of the gas and the deposit became lighter colored, which Hills accounted for by chemical reduction. Willows has repeated Hills' experiments[26] with quartz vacuum tubes, and observes that "a new quartz bulb does not absorb air, but if it be fed with repeated doses of hydrogen—which are absorbed when an electrodeless discharge is passed it then becomes very active. If discharges in hydrogen are alter-

[21] S. E. Hill, Proc. Phys. Soc. London, 35 (1912).
[22] Campbell-Swinton, Proc. Roy. Soc. 79, A, 134 (1907).
[23] Riecke, Ann. d. Phys. 15, 1003 (1904).
[24] F. Soddy and Mackenzie, Proc. Roy. Soc. 80, A, 92 (1908).
[25] J. Am. Chem. Soc. 35, 931 (1913).
[26] Proc. Phys. Soc. London, 28, 124 (1916)

[illegible] bulb can be made [illegible] of either gas and [illegible] gradually increases." [illegible] these results by assum- [illegible] alternate oxidation and [illegible]

[illegible] own that when potassium and [illegible] are used as electrodes, com- [illegible] these metals with hydrogen and nitrogen are formed during the discharge, and [illegible] Gehlhoff[27] has utilized this observation to purify rare gases (Ar, He, Ne, etc). In the presence of a glow discharge with a heated alkali metal as cathode, all the chemically active gases are removed from a mixture of these with the rare gases. Nitrogen is completely absorbed even with the alkali metal at ordinary temperatures. In the case of hydrogen complete absorption occurs with sodium at 290 deg. C., and with potassium at 175 deg. C., while rubidium and caesium are effective at even lower temperatures. Gehlhoff believes that chemical combination occurs between the vapors of the metals and the residual gases in an active state.

The absorption of hydrogen by sodium-potassium electrodes has also been investigated by R. C. Gowdy.[28] Absorption was observed to occur when the alloy was used as cathode, and evolution when used as anode. The hydride is apparently decomposed by the cathode rays.

The most recent work on this subject is that of F. H. Newman.[29] He deposited different elements in a pure condition on the cathode of an electric discharge tube and then determined the absorption of different gases on passing an electric discharge. "Measurements were made to compare the amount of nitrogen gas absorbed by the element in the tube with the quantity of electricity passing in the circuit. Potassium, sodium, mercury, cadmium, antimony, magnesium, calcium, zinc, tin, phosphorus, sulphur, and iodine were tested in this way. The rates of absorption were very great with the last three elements. Hydrogen gas was also used in the tube, and absorption occurred with phosphorus, sulphur, and iodine." Newman concludes from his experiments that the clean-up is due to chemical reactions between the elements present on the cathode and the gases which assume active modifications on the passage of an electric discharge.

[27] Verh. [illegible] 13, 271 (1911).
[28] [illegible] 401 (1913).
[29] [illegible] 13 (1921) p. 60.
[illegible] Jan. (1920).
[30] [illegible] A 229 (1911) and subsequent papers.

In this connection it is interesting to refer briefly to the experiments carried out by R. J. Strutt[30] on the formation and properties of a chemically active modification of nitrogen. He observed that on passing a condenser discharge through nitrogen at low pressures, a form of nitrogen is obtained which shows an intense yellow glow and is very active chemically. As well known, nitrogen in the ordinary state is very inert chemically. It combines with other elements with difficulty and only under special conditions such as high temperature or high pressure. On the other hand, Strutt finds that the nitrogen passed through the discharge tube under the above conditions is very active chemically. "Drawing it by the pump over a small pellet of phosphorus, a violent reaction occurs, red phosphorus is formed, and the yellow glow is quenched. At the same time the gas is absorbed." Similarly active nitrogen combines readily with iodine, sulphur, and arsenic. There is no doubt, therefore, that the formation of active nitrogen must be taken into account in explaining clean-up effects in electrical discharge.

These observations and the results obtained by Langmuir on the electrochemical clean-up of nitrogen by a heated tungsten cathode indicate that the chemical theory probably accounts for some of the clean-up effects observed in discharge tubes. As pointed out by Kaye, "It may be, also, that the action is stimulated by a species of electrolysis of the glass produced by the high-tension discharge playing over its surface. It is well known that glass may be readily electrolysed by quite moderate potentials if the temperature of the glass is raised; and it is a matter of experience that the discharge seems to have an ageing effect on the glass, to the detriment of subsequent working on the blowpipe. Such electrolysis might have a marked effect on the gas film which glass and other solids can condense on their surfaces."

That, however, the clean-up occurs owing to reactions which are not chemical is shown by the fact, observed by Soddy and Mackenzie,[24] that both pure helium and neon are also absorbed in electric discharge tubes. With aluminum electrodes, such as were used in their experiments, the electric discharge causes a considerable mechanical disintegration of the cathode, and the portions of glass adjacent to this electrode become covered with a deposit of the metal in a finely divided state. This phenomenon is known as "cathodic sputtering" and occurs to a larger or smaller extent according to the composition of the cathode.[31]

From the fact that the gases could be recovered by heating the tubes, Soddy and Mackenzie concluded that the gases were mechanically adsorbed by the deposits formed around the cathode. The finely divided metal formed by sputtering is thus assumed to behave like palladium or platinum black in the ordinary adsorption phenomena. That cathodically sputtered metals adsorb hydrogen during discharge has been shown by Heald[32], and other investigators.

C. A. Skinner[33] found in his experiments that gas was evolved at the cathode and absorbed at the anode. The gas evolution occurred at a rate given by Faraday's law, that is, 1 gm. of hydrogen for 96,500 coulombs. It is to be noted that with fresh electrodes a number of observers have found that "there is often an initial evolution of gas, especially in hydrogen and nitrogen, or in any gas, with aluminum electrodes. But if the tube is used and then allowed to stand awhile, on restoring the current, no initial evolution is found in most cases."

L. V. Chrisler[20] has also concluded that the absorption in the discharge tube occurs at the anode. On the other hand, the weight of evidence points to the predominating influence of the cathode on the amount and rate of absorption. B. Hodgson[19] and S. Brodetsky and Hodgson[15] have investigated the relation between amount of clean-up and current, and also the effect of varying the chemical composition of the electrodes. The amount of gas absorbed per coulomb was observed to increase with decrease in pressure, as had previously been observed by Willows. The pressures at which these experiments were carried out varied from 2 mm. to 0.03 mm. approximately. A battery giving about 3200 volts was used as source of current, and the actual current strength varied from 0.008 to 0.002 amp. They found that the absorption varied with the rate of disintegration of the cathode, and no absorption was obtained in absence of such disintegration. Furthermore, the absorption was observed to increase with increase in cathode drop. They therefore concluded, in agreement with Soddy and Mackenzie, that the major portion of the clean-up is due to adsorption of the gas by the metal sputtered from the cathode.

These observations have been confirmed to a large extent by L. Vegard.[34] He finds that absorption is small as long as the cathode drop is below a certain "threshold" value, and he connects the clean-up with cathodic sputtering. The absorption rate follows the cathode drop and runs parallel with the amount of cathodic sputtering. Thus, in oxygen gold electrodes show more sputtering than electrodes of platinum. At the same time, the rate of clean-up is greater with gold than with platinum. Vegard also observed that in the case of helium there is a measurable clean-up which is, however, less than that obtained under similar conditions with either nitrogen or oxygen. In the case of hydrogen both absorption and evolution were found to occur. "When a current of definite value has reduced the pressure to a given value, a larger current causes evolution, and a smaller one, absorption." This probably accounts to a certain extent for Skinner's observations.[33] Vegard concludes from his experiments that absorption occurs at the cathode and is somehow caused by high velocity positive ions impinging on the cathode. In other words, his explanation attempts to straddle both the chemical and mechanical theories.

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31 See Kaye's "X-Rays," Chapt. VII for a description of the phenomenon.

32 Phys. Rev. *24*, 269 (1907).

33 Phil. Mag. *12*, 481 (1906); Phys. Rev. *21*, 1,169 (1905); Phys. Zeits. *6*, 610 (1905).

34 Ann. d. Physik, *50*, 769 (1916).

High Frequency Absorbers

PART I

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[illegible] waves and the effect of concentrated capacitance and inductance have been discussed [illegible] the Review. The present article discusses the effect of resistance in series [illegible] "high-frequency absorber." It is shown that such an absorber is a valuable [illegible]r in protecting against those transient disturbances which are of too low voltage [illegible] which may still be dangerous because of steep wave front and because under [illegible] in the building up of local oscillations. In Part II the inductance-resistance [illegible] considered. Editor.

Resistances in combination with condensers and inductances are used to absorb the energy of high frequency oscillations and of traveling waves.* These combinations, popularly called "high-frequency absorbers," prevent the building-up of oscillations in the windings of transformers and generators, since if the source of the high frequency oscillations is of small energy the dissipation of energy in the resistance holds down the line oscillations to very small values. They also modify the phenomena of transmission and reflection of traveling waves along transmission lines, especially at the wave fronts, substantially decreasing the possible dangers resulting from steep waves. The deformations produced at the front of rectangular waves by a condenser connected in shunt with the line or by an inductance connected in series with the line have been studied by different investigators and are well known. This article will treat of the influence resulting from the addition of a resistance in series with the condenser and the addition of a resistance in shunt with the inductance, special attention being given to the absorption of energy by these resistances.

It will be noted that high frequency oscillations are assumed to be undamped and that traveling waves are assumed to possess rectangular fronts. These assumptions, especially the latter, are made in order to simplify calculations, although they represent limit cases that do not occur in practice. Their study, however, will give results which properly interpreted are applicable to phenomena actually occurring in the high tension systems.

* These combinations were first proposed by G. Campos.

Condenser-resistance

Let us discuss first the absorber constituted by a resistance in series with a condenser and connected across line conductors or from line conductors to ground.

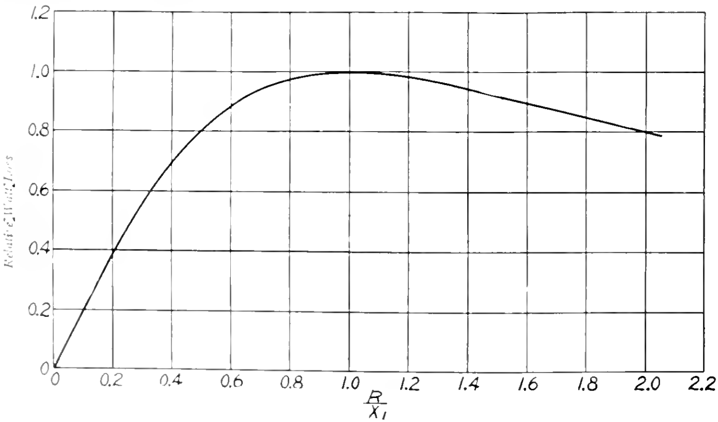

Fig. 1

The action of this device will be investigated in connection with:

(a) Sustained oscillations.

(b) Rectangular waves of different lengths.

(a) With a given condenser and a high frequency oscillation of given voltage, the dissipation of energy varies with the resistance and the frequency. Assuming that the oscillation is "sustained," the current is:

$$I = \frac{E}{\sqrt{R^2+X^2}}$$

where R is the value of the resistance in series with the condenser, X is the reactance of the condenser, and E the voltage of the oscillation. Therefore the watts loss is:

$$RI^2 = E^2\frac{R}{R^2+X^2}$$

This loss is a maximum for $R=X$, as can be proved by considering that the maximum loss occurs when

$$\frac{\delta}{\delta R}\left(\frac{R}{R^2+X^2}\right)=0$$

or

$$R^2+X^2-2R^2=0$$

Hence $\qquad R=X$

With a given reactance X_1 the maximum loss is

$$RI^2\,(max.) = \frac{E^2}{2X_1}$$

Let $a=\frac{R}{X_1}$, and substitute in the general equation.

Then

$$RI^2 = \frac{E^2}{2X_1}\left(\frac{2a}{a^2+1}\right)$$

The relative RI^2 loss for various values of a is plotted in Fig. 1. This curve shows that the loss is a maximum for $R=X$, but that R may be varied over quite a wide range for a given value of X without greatly decreasing the loss.

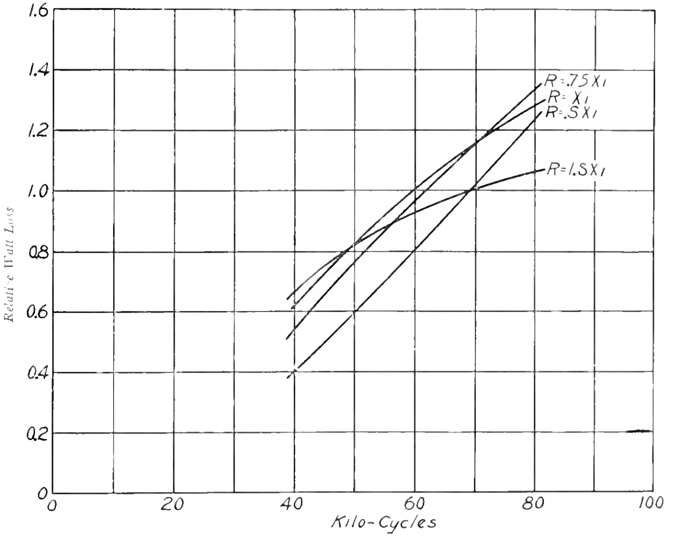

Fig. 2

The frequencies at which dangerous local oscillations may be built up in windings cover a small range, of which the average is about 60 kilocycles. Fig. 2 shows the variation of the resistance loss with the frequency for various values of R. X_1 is the capacity reactance at 60 kilocycles. The loss is plotted to the same scale as in Fig. 1. These two figures show that R may be chosen considerably less or greater than X, without greatly decreasing the resistance loss, if it is found to be advisable for other reasons.

... case of steep ... comparatively short duration ... wave as passing the ... of natural impedance ... natural impedance Z_2 as ...

Fig. 3

In studying the effect of the resistance, we will consider a high frequency absorber having a capacitance of 2×10^{-8} farads and used on a transmission line having a natural impedance Z_1 of 300 ohms.

Three cases will be considered:

1. Z_2 is equal to $10Z_1$ or 3000 ohms, and represents a transformer.
2. Z_2 is equal to Z_1 or 300 ohms, *i.e.*, the circuit has the same constant on both sides of the absorber.
3. Z_2 is equal to $0.1Z_1$ or 30 ohms, and represents a cable.

In all these cases the traveling wave is taken with a vertical front, with a voltage P_1 and a current I_1.

When the wave comes to the absorber from Z_1, the wave energy $W_1 = P_1 I_1 t$ is divided. A part W_2 is transmitted. A part W_r is reflected. A part W_s is temporarily stored in the condenser. A part W_R is dissipated or absorbed in the resistance of the high frequency absorber.

The general equation for W_R from time 0 to time t is

$$W_R = P_1 I_1 C^2 R B \frac{2 Z_1 Z_2^2}{(Z_1 + Z_2)^2} (1 - \epsilon^{-2Bt})$$

where

$$B = -\frac{1}{C\left(R + \frac{Z_1 Z_2}{Z_1 + Z_2}\right)} \quad \text{(See Appendix 1)}$$

In order to have a general idea of the order of magnitude of the duration of this phenomenon, it will be well to consider that, if the resistance loss would continue at its initial rate $\left(\text{which is } P_1 I_1 C^2 R B^2 \frac{4 Z_1 Z_2^2}{(Z_1 + Z_2)^2}\right)$ during the time $\frac{1}{2B}$ the energy consumption

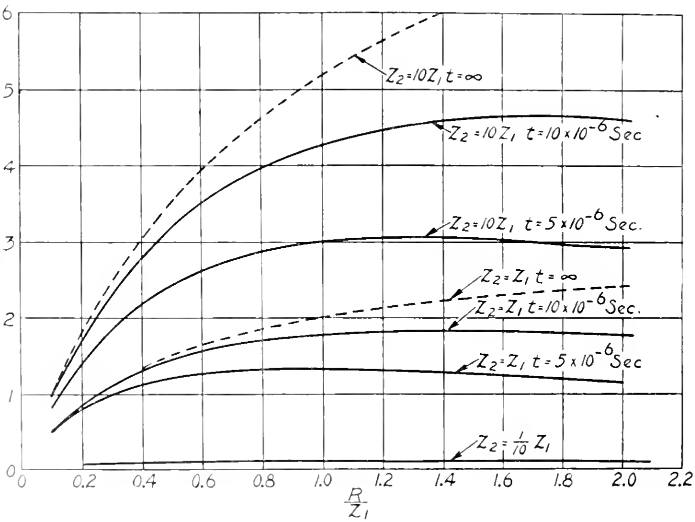

Fig. 4

would be equal to W_R from t equals 0 to t equals infinity. Let us assume for simplicity

$$Z_1 = Z_2 = R = 300 \text{ ohms}$$

then

$$\frac{1}{2B} = T = 4.5\ 10^{-6} \text{ seconds.}$$

Fig. 4 shows the energy dissipated in the resistance in terms of the energy in 1000 ft. of the incoming wave, that is, $\frac{W_R}{P_1 I_1 10^{-6}}$, for various values of R in terms of Z_1, with $Z_1 = 300$ ohms and $C = 2 \times 10^{-8}$ farads. The dotted lines show the total dissipation for a wave of infinite length. The solid line curves show the dissipation during 5 and 10 micro-seconds. These 10,000 ft. long is approximately as great as the dissipation for longer waves. Thus the absorber considered in calculating these curves is most efficient for waves of 10,000 ft. length or less. If it were desired to dissipate more energy from waves of longer length it would be necessary to use a larger absorber.

At the end of the wave, the condenser discharges. Part of the stored energy W_c is then transmitted back to lines Z_1 and Z_2 and a part is absorbed in the resistance. The sum of this absorbed energy and W_R is W'_R.

Figs. 6, 7, and 8 show how the energy of a 5000-ft. wave on a transmission line divides at the absorber, for the three values of Z_2, with $Z_1 = 300$ ohms and $C = 2 \times 10^{-8}$ farads.

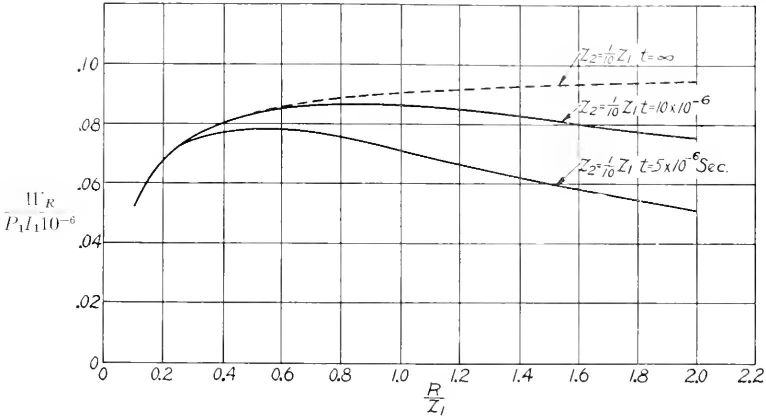

Fig. 5

time intervals correspond to wave lengths on the transmission line of 5000 and 10,000 ft., respectively. In Fig. 5 the curve for $Z_2 = 0.1 Z_1$ is plotted to a larger scale.

The total energy in two such rectangular waves is 5 $P_1 I_1$ 10^{-6} and 10 $P_1 I_1$ 10^{-6} watt-seconds or joules. These curves show that a large percentage of the energy of these short waves may be dissipated by high frequency absorbers such as the one selected in this case. The curves also show that the value of R may be varied considerably without greatly decreasing the dissipation of wave energy. The effect of variation of R upon the flattening of the wave front is considered later. The curves are changed very little if Z_2 is chosen greater than $10 Z_1$. If R is equal to Z_1 or less, the dissipation of energy for a wave

Where Z_2 is large in comparison with Z (Fig. 6) a large percentage of the energy of W_1 is absorbed. Where Z_2 is small in comparison with Z_1 (Fig. 8), nearly all the energy is transmitted or reflected and the absorber has little effect on waves in that direction.

The curves of Figs. 4 to 8 inclusive refer to waves on a transmission line. A value of C has been used which is one of the smaller values used in modern high frequency absorbers. The mathematical equations for all of these curves are given in Appendix 1.

Similar curves can also be plotted for waves in a cable where Z_1 is much smaller than in a transmission line. In this case it is found, as before, that a large energy absorption may be obtained for a wave passing the absorber to a circuit where Z_2 is large in

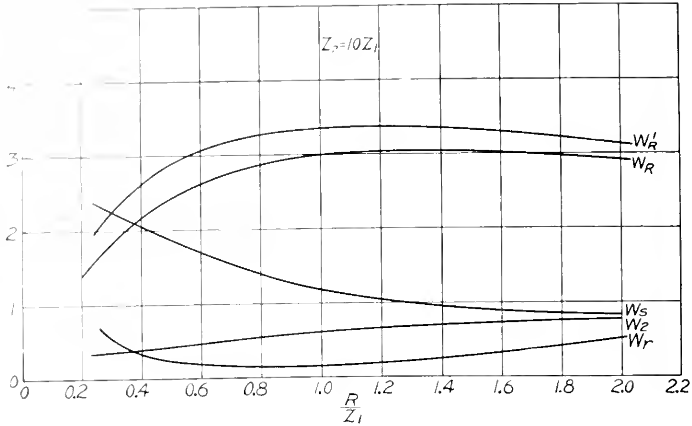

Fig. 6

comparison with Z_1. A larger condenser, however, is required in the case of the cable than in the case of the transmission line.

A simple numerical example will be instructive and is therefore worked out below.

The formulae given in Appendix 1 are used and no further explanation seems necessary except perhaps to point out that at t equal zero, all the conditions are the same as if the resistance R alone were connected across the line, whereas final conditions are the same as if no extra device were connected across the line.

Let us assume

$$Z_1 = 500 \text{ ohms}$$
$$Z_2 = 2000 \text{ ohms}$$
$$C = 2 \times 10^{-8} \text{ farads}$$
$$R = \frac{Z_1 Z_2}{Z_1 + Z_2} = 400 \text{ ohms}$$

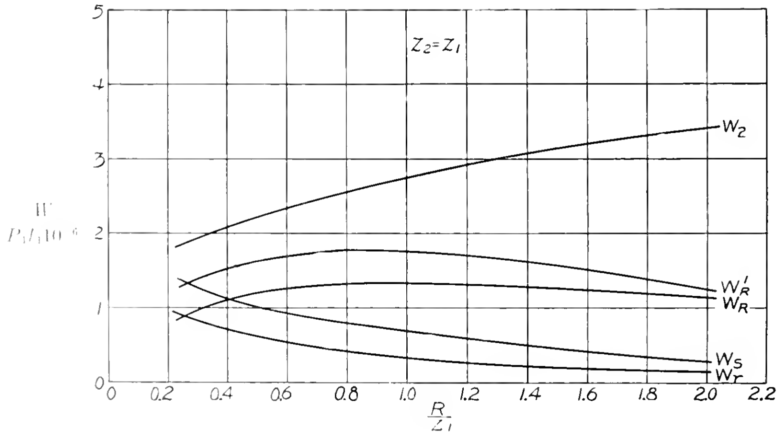

Fig. 7

This value of the resistance is chosen because it gives the maximum rate of dissipation of energy at t equal zero.

The incoming wave has

$$P_1=10^5 \text{ volts}$$

$$I_1=\frac{10^5}{500}=200 \text{ amperes}$$

The energy per 1000 ft. of the incoming wave is (since the wave travels 1000 ft. in 1 microsecond),

$$P_1I_1\ 10^{-6}=20 \text{ watt-seconds.}$$

To facilitate the calculations, we will first find

$$B=\frac{10^8}{2(400+400)}=\frac{1}{16\times10^{-6}} \qquad \text{See (5)}$$

Regarding "energies," if the absorber were omitted the part $\frac{4Z_1Z_2}{(Z_1+Z_2)^2}=0.64$ of the incoming energy would be transmitted and the part $\left(\frac{Z_2-Z_1}{Z_2+Z_1}\right)^2=0.36$ of the incoming energy would be reflected, and the wave fronts would remain vertical. See (15) and (16) for $M=0$.

The "absorber," we know, dissipates part of the energy and modifies the wave fronts.

Comparing the action at the wave fronts by the absorber having $C=2\times10^{-8}$ farads and $R=400$ ohms with the action of the simple condenser of the same capacity 2×10^{-8} farads, we tabulate the energies that modify the fronts and tails of the waves as follows:

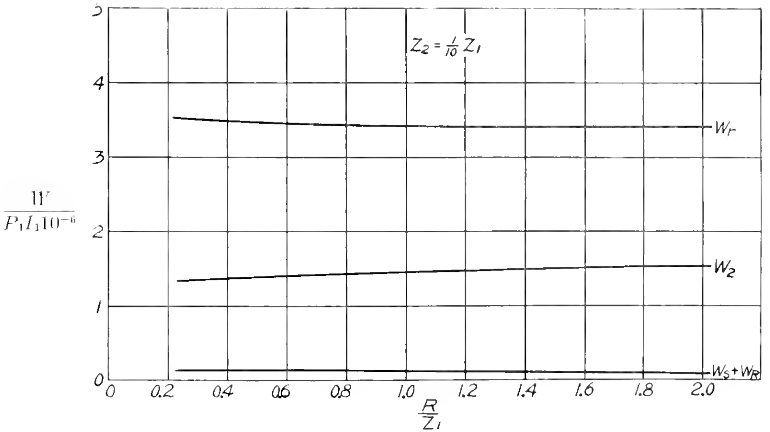

Fig. 8

$$CRB=2\times400\frac{10^8}{16\times10^{-6}}=\frac{1}{2}$$

$$M=2\times10^7\times2\times10^{-8}\frac{2\times500\times4\times10^{-6}}{(25)^3\times10^6}$$

$$=0.1024 \qquad \text{See (19)}$$

The voltage P_2 of the transmitted wave goes from

$$P_1\frac{4000}{2500}\left(1-\frac{1}{2}\right)=0.8\ P_1 \text{ at } t=0$$

$$\text{to } 1.6\ P_1 \text{ at } t=\infty \qquad \text{See (8)}$$

The voltage P_r of the reflected wave goes from

$$P_1\left(\frac{1500}{2500}-\frac{1.6}{2}\right)=-0.2\ P_1 \text{ at } t=0$$

$$\text{to} -0.6P_1 \text{ at } t=\infty \qquad \text{See (9)}$$

See from (15) to (18) and from (27) to (29).

$R=0$	$R=400$
FRONT	
$W_2=0.64P_1I_1t-153.6$	$W_2=0.64P_1I_1t-179.2$
$W_r=0.36P_1I_1t-102.4$	$W_r=0.36P_1I_1t-204.8$
$W_S=256$	$W_S=256$
$W_R=0$	$W_R=128$
TAIL	
$\overline{W}_2=51.2$	$\overline{W}_2=25.6$
$\overline{W}_r=204.8$	$\overline{W}_r=102.4$
$\overline{W}_R=0$	$\overline{W}_R=128$

A [illegible] energies assume the [illegible] above tabulation [illegible] wave fronts are [illegible] therefore, as far [illegible] concerned, t can be [illegible] For instance if W_R would [illegible] rate as at t equal zero, [illegible] maximum value after a [illegible] 8 micro-seconds.

[illegible] tabulation shows that if no resistance [illegible] connected in series with the condenser, 153.6 watt-seconds are taken from the fronts of the transmitted waves and 102.4 watt-seconds are taken from the fronts of the reflected waves; these 256 watt-seconds being stored in the condenser. If a resistance $R = 400$ ohms is connected in series with the condenser, then 179.2 watt-seconds are taken from the fronts of the transmitted waves and 204.8 watt-seconds are taken from the fronts of the reflected waves. Of these 384 watt-seconds, 256 are stored in the condenser and 128 are dissipated by the resistance. At the end of the waves, if the condenser is alone, of the 256 watt-seconds stored in it, 51.2 are returned to the circuit Z_2, 204.8 to the circuit Z_1. If a resistance of 400 ohms is connected in series with the condenser, of the 256 watt-seconds stored in the condenser 25.6 are returned to the circuit Z_2, 102.4 are returned to the circuit Z_1 and 128 are dissipated in the resistance R.

We have seen that the energy of a thousand feet of the incoming wave is 20 watt-seconds, therefore, the amount of energy dissipated in the resistance R, at the front and tail of the wave, is equivalent to the energy of 12,800 feet of the incoming wave.

It will be interesting to repeat the calculations for a wave traversing the same circuits as before but in the opposite direction. We will then have

$$Z_1 = 2000 \text{ ohms}$$
$$Z_2 = 500 \text{ ohms}$$
$$C = 2 \times 10^{-8} \text{ farads}$$
$$R = 400 \text{ ohms}$$

We assume again the voltage of the incoming wave to be $P_1 = 10^5$ volts.

The current of the incoming wave will then be $I_1 = \frac{P_1}{2000} = 50$ amperes.

The energy per micro-second or per 1000 feet of the incoming wave is $P_1 I_1 10^{-6} = 5$ watt-seconds. In this case, B is again $\frac{1}{16 \times 10^{-6}}$.

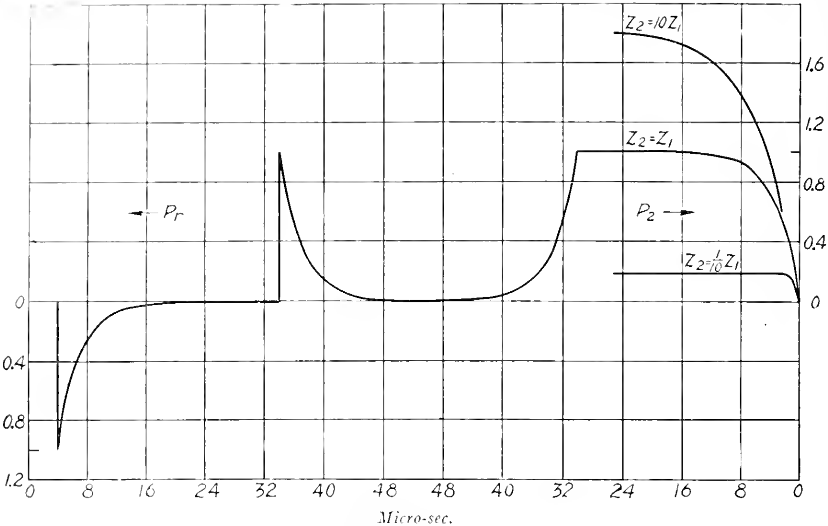

Fig. 9. Curves Based on Value of $P_1 = 1$

The transmitted voltage P_2 goes from $P_1 \frac{1000}{2500} \times 1/2 = 0.2 P_1$ at $t=0$ to $0.4 P_1$ at $t=\infty$. See (8)

The reflected wave goes from $P_1 \left(-\frac{1500}{2500} - \frac{0.4}{2}\right) = -0.8\ P_1$ at $t=0$ to $-0.6\ P_1$ at $t=\infty$. See (9)

In this case, $M=0.0064$. See (19)

If there were no absorber, the energy of the incoming wave would again be divided as follows: 64 per cent would be transmitted and 36 per cent would be reflected.

The energies at the fronts and at the tails of the waves, when the condenser alone (2×10^{-8} farads) and when the condenser-resistance ($C=2\times 10^{-8}$ farads and $R=400$ ohms) are used may be tabulated as follows:

$M=0.0064$

$R=0$	$R=400$
Front	
$W_2=0.64P_1I_1t-38.4$	$W_2=0.64P_1I_1t-44.8$
$W_r=0.36P_1I_1t+22.4$	$W_r=0.36P_1I_1t+20.8$
$W_S=16$	$W_S=16$
$W_R=0$	$W_R=8$
Tail	
$\overline{W}_2=12.8$	$\overline{W}_2=6.4$
$\overline{W}_r=3.2$	$\overline{W}_r=1.6$
$\overline{W}_R=0$	$\overline{W}_R=8$

In this case, when the condenser is alone, 38.4 watt-seconds are taken from the fronts of the transmitted waves and 22.4 watt-seconds are reflected back into line Z_1 and 16 are stored in the condenser. When a resistance of 400 ohms is connected in series with the condenser then 44.8 watt-seconds are taken from the front of the transmitted wave, 20.8 watt-seconds are reflected back into circuit Z_1, 16 watt-seconds are stored in the condenser and 8 watt-seconds are dissipated in the resistance.

At the end of the wave, if no condenser is used, of the 16 watt-seconds stored in the condenser, 12.8 are returned to line Z_2 and 3.2 to line Z_1. If a resistance of 400 ohms is used in series with the condenser, of the 16 watt-seconds stored in the condenser, 6.4 are returned to line Z_2, 1.6 are returned to line Z_1 and 8 are dissipated in the resistance R. The resistance, therefore, dissipates a total of 16 watt-seconds equivalent to the energy of 3200 feet of the incoming wave. The same absorber, we have seen before, dissipates 256 watt-seconds when the wave passed from the circuit of 500 ohms impedance to the circuit of 2000 ohms impedance. The amount of energy dissipated in the latter case is 16 times the amount dissipated when the wave passes from the circuit of higher impedance to the circuit of lower impedance. However, since the energy per unit length of the traveling wave passing from the circuit of lower impedance to the circuit of higher impedance is 4 times that of the wave traveling in the opposite direction, we may say that the

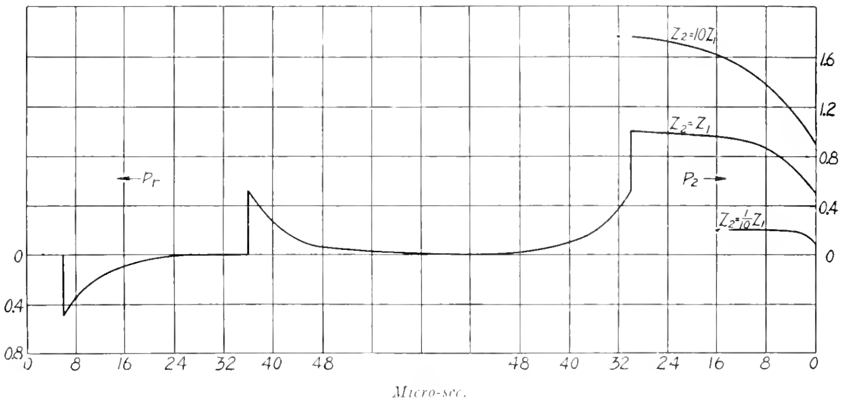

Fig. 10. Curves Based on Value of $P_1=1$

[illegible] is 4 times [illegible] from the 500 [illegible] than when it [illegible] to the 500 ohms [illegible] "relative" ab- [illegible] ortional to Z_2, call- [illegible] circuit into which [illegible]

[illegible] limited to this par- [illegible] general. In fact, the [illegible] dissipated in the [illegible] front and the energy [illegible] incoming wave is [See (14).]

$$[illegible] \frac{2 Z_1 Z_2^2}{(Z_1+Z_2)^2} [illegible] = RC^2B \frac{2 Z_1 Z_2}{(Z_1+Z_2)^2} 10^6 Z_2$$

impedance of the line. If the wave length is short, the condenser will also reduce the crest value of the transient voltage at the point where it is connected. The effect of the condenser without series resistance upon an incoming rectangular wave of voltage P_1 (taken equal to 1) is shown in Fig. 9 for a circuit $Z_1=300$ ohms and a condenser $C=2\times10^{-8}$ farads. Three values of Z_2 are considered as before, but to avoid confusion the entire wave (transmitted P_2 and reflected P_r) is plotted only for the case $Z_2=Z_1$. The other waves are similar. Time is used for abscissae because the velocity of the wave varies. The velocity is about 1000 ft. per micro-second on a transmission line but is less in a cable or transformer. When a resistance is connected

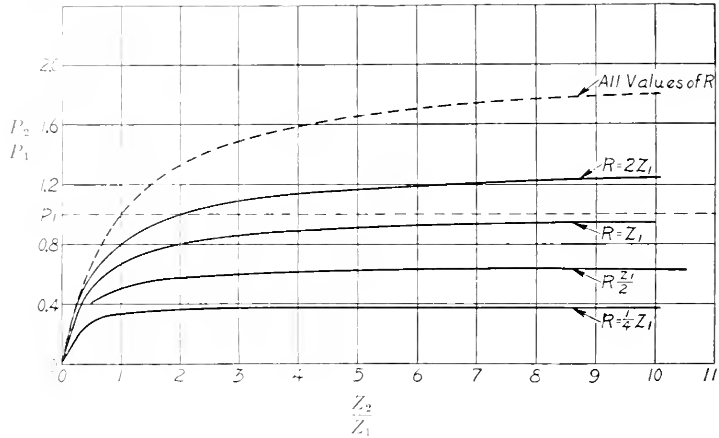

Fig. 11

Now, the factor that multiplies Z_2 is the same whether the wave travels in one direction or in the opposite direction. The same conclusion applies to the energy at the tail of the wave.

That this type of absorber dissipates relatively more energy when the wave passes from the lower to the higher impedance circuit has also been shown in the preceding curves.

Condensers without series resistance have been used (principally in Europe) to flatten out steep wave fronts of traveling waves. The condenser flattens out the wave because the voltage can rise at the condenser only as fast as the condenser can be charged and the charging current which is taken from the [illegible] wave is limited by the natural in series with the condenser, the conditions are changed because energy is dissipated both at the wave front, while the condenser is storing energy, and at the end of the wave when the stored energy flows back into the lines.

Fig. 10 shows the effect of a condenser-resistance upon a rectangular traveling wave, for $R=Z_1=300$ ohms and with the same condenser and circuits as in Fig. 9. The voltage at the condenser-resistance starts at about half the value that it would if there were no protective device, in the case of $Z_2=10Z_1$. The condenser without resistance causes the voltage to start at zero. Thus if we consider that the condenser reduces the starting voltage on circuit 2 by 100 per cent, then with the resistance $R=Z_1$ the starting voltage is reduced 50 per cent.

The effect upon P_2 of using other values of R is shown in Fig. 11. The dotted line shows the crest voltages for a long wave while the solid lines show the starting voltages for various values of R. With $R=0.5Z_1$ the starting voltage is reduced about 75 per cent. This means that the condenser-resistance will give a high degree of protection to a transformer against steep wave fronts with a resistance value which has been shown to be very efficient as an absorber of the energy of high frequency oscillations and short traveling waves.

The particular cases investigated above seem sufficient to give a general idea of the phenomena involved.

While absorbers have been shown to be effective for a wide range in the value of series resistance, the lower values of resistance such as $R=\frac{Z_1}{2}$ are best from the standpoint of protection against steep wave fronts. The use of some resistance is advisable to prevent the condenser itself becoming a source of trouble as in the case of an arc near the condenser where the charge and discharge of the condenser would not be limited by the natural impedance of the line.

(To be continued)

APPENDIX I

The fundamental equations of a rectangular wave passing from a circuit of natural impedance Z_1, past a condenser-resistance, to a circuit of natural impedance Z_2 (see Fig. 3) are

$$I_1=I_2+I_c+I_r \qquad P_2=I_2Z_2 \qquad (1)$$

$$P_2=P_1+P_r=P_c+RI_c \qquad P_1=I_1Z_1 \qquad (2)$$

$$I_c=C\frac{dP_c}{dt} \qquad P_r=I_rZ_1 \qquad (3)$$

where

P_1 and I_1 are respectively the voltage and current of the incident wave.

P_2 and I_2 the voltage and current of the transmitted wave.

P_r and I_r the voltage and current of the reflected wave.

C the capacity of the condenser.

R the value of the resistance in series with the condenser.

I_c the current through condenser and resistance.

P_c the voltage across the condenser.

I_R the current through the resistance R. $I_R=I_c$

Substituting in equation (1) and re-arranging, we have

$$\frac{dP_c}{dt}+P_cB=2P_1B\frac{Z_2}{Z_1+Z_2} \qquad (4)$$

where

$$B=\frac{1}{C\left(R+\frac{Z_1Z_2}{Z_1+Z_2}\right)} \qquad (5)$$

Integrating (4) gives

$$P_c=P_1\frac{2Z_2}{Z_1+Z_2}(1-\epsilon^{-Bt}) \qquad (6)$$

$$I_c=C\frac{dP_c}{dt}=P_1\frac{2Z_2}{Z_1+Z_2}CB\epsilon^{-Bt} \qquad (7)$$

Substituting in equation (2), we have

$$P_2=P_1\frac{2Z_2}{Z_1+Z_2}\left(1-CB\frac{Z_1Z_2}{Z_1+Z_2}\epsilon^{-Bt}\right) \qquad (8)$$

$$P_r=P_1\left[\frac{Z_2-Z_1}{Z_1+Z_2}-\frac{2Z_1Z_2^2}{(Z_1+Z_2)^2}CB\epsilon^{-Bt}\right] \qquad (9)$$

The equations for the energies are (in watt-seconds or joules) for the incident wave,

$$W_1=P_1I_1\,t \qquad (10)$$

For the transmitted wave,

$$W_2=\int_0^t P_2I_2\,dt$$

Therefore

$$W_2=P_1I_1\left[\frac{4Z_1Z_2}{(Z_1+Z_2)^2}t-C\frac{8Z_1^2Z_2^2}{(Z_1+Z_2)^3}(1-\epsilon^{-Bt})\right.$$
$$\left.+C^2B\frac{2Z_1^3Z_2^3}{(Z_1+Z_2)^4}(1-\epsilon^{-2Bt})\right] \qquad (11)$$

For the reflected wave

$$W_r=\int_0^t P_rI_r\,dt$$

Therefore

$$W_r=P_1I_1\left[\left(\frac{Z_2-Z_1}{Z_1+Z_2}\right)^2t-C\frac{4Z_1Z_2^2(Z_2-Z_1)}{(Z_1+Z_2)^3}\right.$$
$$\left.(1-\epsilon^{-Bt})+C^2B\frac{2Z_1^2Z_2^4}{(Z_1+Z_2)^4}(1-\epsilon^{-2Bt})\right] \qquad (12)$$

The energy stored in the condenser is

$$W_s=\frac{1}{2}CP_c^2$$

Therefore

$$W_s=P_1I_1C\frac{2Z_1Z_2^2}{(Z_1+Z_2)^2}(1-\epsilon^{-Bt})^2 \qquad (13)$$

The energy dissipated in the resistance is

$$W_R=\int_0^t RI_c^2dt$$

Therefore

$$W_R=P_1I_1RC^2B\frac{2Z_1Z_2^2}{(Z_1+Z_2)^2}(1-\epsilon^{-2Bt}) \qquad (14)$$

If the wave is "long" and the time t is taken "late" enough to have the phenomena at the fronts of the waves practically completed, that is to say, if, at the time t, the [illegible] an open circuit, [illegible] may be extended [illegible] energies may be [illegible]

$$[illegible]\ M\left[\ [illegible] - \frac{2 [illegible] Z_2}{Z_1+Z_2}CB\right] \quad (15)$$

$$[illegible] = P_1 I_1 \frac{Z_2 \ [illegible] Z_1)^2}{(Z_1+Z_2)^2} t - [illegible]$$

$$M\left[2Z_2 - 2Z_1 - \frac{Z_1Z_2^2}{Z_1+Z_2}CB\right] \quad (16)$$

$$W_c = M[Z_1+Z_2] \quad (17)$$

$$W_R = M[Z_1+Z_2]RCB \quad (18)$$

where

$$M = P_1 I_1 C\frac{2Z_1Z_2^2}{(Z_1+Z_2)^3} \quad (19)$$

It will be noted that

$$W_1 = W_2 + W_r + W_c + W_R$$

and that the sum of the terms containing M (which terms affect the phenomena at the wave fronts) is zero. If no condenser were connected, then C would be 0 and M would be 0 and no deformation of wave fronts would take place. For the generality of the formulae, it may be interesting to add that, if no resistance R were used, then R would be 0 and we would have

$$B = \frac{Z_1+Z_2}{CZ_1Z_2}$$

At "the end of the wave," the condenser discharges into lines Z_1 and Z_2 in parallel through the resistance R, *i.e.*, the condenser discharges in a circuit of resistance $R+\frac{Z_1Z_2}{Z_1+Z_2}$.

We will treat the simple case when the wave ends after the condenser has practically received the full charge and therefore all voltages and currents have reached their final values.

During the discharge of the condenser, we will then have

$$P_c = P_1\frac{2Z_2}{Z_1+Z_2}\epsilon^{-Bt} \quad (20)$$

$$I_c = -C\frac{dP_c}{dt} = P_1\frac{2Z_2}{Z_1+Z_2}CB\epsilon^{-Bt} \quad (21)$$

$$P_2 = P_c - I_c\frac{Z_1Z_2}{Z_1+Z_2} = P_1\frac{2Z_1Z_2^2}{(Z_1+Z_2)^2}CB\epsilon^{-Bt} \quad (22)$$

It will be noted that the difference between P_c and P_2 or P_r is RI_c

$$I_r = \frac{P_r}{Z_1} \text{ and } I_2 = \frac{P_2}{Z_2} \text{ as before}$$

$$\frac{I_r}{I_2} = \frac{Z_2}{Z_1} \quad (23)$$

The energy stored in the condenser is

$$W_c = M(Z_1+Z_2) \qquad \text{See (17)}$$

The part of this energy returned to line 2 is

$$\overline{W}_2 = \int_o^\infty P_2 I_2\, dt$$

The time is now counted from the vertical end of the incoming wave.

$$\overline{W}_2 = P_1 I_1 \frac{2Z_1^3Z_2^3}{(Z_1+Z_2)^4}C^2B \quad (24)$$

The part of the stored energy returned to line 1 is

$$\overline{W}_r = \int_o^\infty P_r I_r dt$$

Therefore

$$\overline{W}_r = P_1 I_1 \frac{2Z_1^2Z_2^4}{(Z_1+Z_2)^4}C^2B \quad (25)$$

The energy dissipated in the resistance R during the discharge is

$$\overline{W}_r = R\int_o^\infty I_c^2 dt = P_1 I_1 \frac{2Z_1Z_2^2}{(Z_1+Z_2)^2}RC^2B \quad (26)$$

It will be noted that the same amount of energy was dissipated by R at the front of a "long" wave. See (14).

Collecting again M as before, we tabulate the energies at the tail of the wave as follows:

Stored in the condenser

$$W_c = M(Z_1+Z_2) \qquad \text{See (17)}$$

Returned to line 2

$$\overline{W}_2 = M\frac{Z_1^2Z_2}{Z_1+Z_2}CB \quad (27)$$

Returned to line 1

$$\overline{W}_r = M\frac{Z_1Z_2^2}{Z_1+Z_2}CB \quad (28)$$

Absorbed by R

$$\overline{W}_R = M(Z_1+Z_2)RCB \quad (29)$$

Photo-elasticity for Engineers

PART V. THE STRESS-STRAIN PROPERTIES OF NITRO-CELLULOSE AND THE LAW OF ITS OPTICAL BEHAVIOR

By E. G. Coker, D.Sc., F.R.S.

This article is the last of a series of five by Dr. E. G. Coker, F. R. S., on the photo-elastic method of stress analysis. It is devoted entirely to a study of nitro-cellulose, or celluloid, to find out whether the light retardation is produced by stress or by strain, and whether the law followed is linear or a more complicated one. It is concluded that all evidence in this investigation shows that the retardation is directly proportional to stress within the limits of error of the experiment.—Editor.

The mechanical and optical properties of nitro-cellulose have not so far been examined in very great detail, and this installment describes some experimental evidence which has been recently obtained and which will be extended as opportunity occurs, since this has an important bearing on the study of stress problems arising in engineering practice.

The principal matters which have been examined are the mechanical properties of nitro-cellulose under pure tensile and bending stresses and the laws of its optical behavior under these kinds of stress. In the course of the experimental study a considerable number of specimens have been examined, all of which were manufactured by the British Xylonite Company.

The salient features of the material are its great flexibility and toughness, and the ease with which it can be drilled, turned or machined. By suitable adjustment of the condition of nitration of the body, the hardness of the material can be varied through a considerable range, but owing to the difficulties created by the stress of war conditions it has not been possible to make the investigations cover materials possessing a great range of hardness. In fact all the specimens which have been examined were originally selected on account of their transparency and freedom from initial stress. The sheets from which the specimens were made differed greatly in age; one had been in stock for at least eight years, and most of the others had been stored one or more years.

In order to examine the stress-strain properties of this material it is unnecessary to use a very delicate extensometer as the value of the modulus for direct stress is comparatively small, and for the purposes of these experiments a very simple form was employed consisting of a pair of clips attached respectively to a scale and a pointer, which latter slides over the scale and is kept in contact with it by suitable attachments. In order to examine the optical properties of the material while under stress, both scale and pointer were perforated to give a window opening, and thereby permit a beam of polarized light to be transmitted through the specimen under examination. With this instrument and special magnifying devices it was possible to estimate extensions of 0.0002 inch.

A preliminary examination of the problem as set out may be described with reference to some experiments on a specimen which was originally used in 1911 for determining the stresses in a notched tension member.

Two bars, each 1 inch wide, were cut at that time from a clear plate of xylonite $\frac{3}{16}$ inch thick, and each was fashioned with notches of different sizes along the edges. One of these specimens has been used for the present test. A length of 6 inches was used for observations of the longitudinal strains, while the lateral strains required for determining Poisson's ratio $\frac{1}{m} = \sigma$, were measured by aid of the strain measuring apparatus already described. Unless otherwise stated these latter measurements were in the direction of the thickness of the material.

Longitudinal Extension.—The specimen was examined in the polariscope under a moderate load, and it was found that the stress was very uniformly distributed over a length of $6\frac{1}{2}$ inches, but the remaining part of the parallel portion showed signs of unequal stress distribution owing to the enlarged ends. It was therefore marked off approximately into half-inch lengths, over a total length of 6 inches, the exact distance being read to 1/1000 inches.

Young's Modulus.—As it is convenient to start with a load of 20 lbs. on the specimen, a preliminary observation is made to determine the corresponding extension, and this value was allowed for in subsequent readings for convenience in plotting from a zero strain value.

[illegible] ons are shown in [illegible] 20-lb. increments. [illegible] aried from 160 lbs. [illegible] strains reached their [illegible] again taken to their [illegible] ale read to note the [illegible] The time interval [illegible] loads varied from one to [illegible] It was found that the stress- [illegible] obtained were approxi- [illegible] near, except at the highest values, [illegible] der to obtain as correct a value of

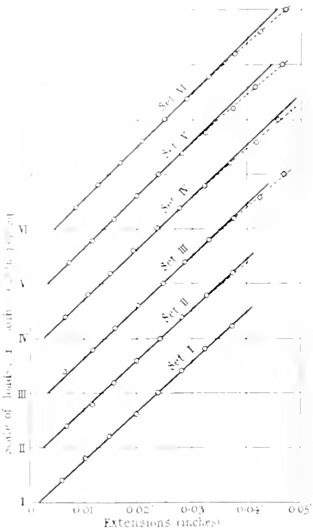

Fig. 1

Young's modulus E, as possible, only measurements between 40 and 140-lb. load were used, as the readings between these points were considered to be the most reliable. The strain corresponding to this difference of stress of 1256 lbs. per sq. in. was found to be 0.00354 in. giving a value of $E = 355{,}000$.

It will be observed that the elastic limit is not very pronounced and that the curve is nearly straight up to 150-lb. load (1900 lb. in.^{2}) which latter value may be taken as the elastic limit of the material. There was a "semi-permanent" set of 0.001 in. for each repetition of load, and a pronounced recovery between successive loadings, especially with a short period of rest.

The experiments were continued until a maximum load of 476 lbs. was reached corresponding to a stress of 6000 lbs. per sq. in., but as the extension then increased very rapidly it was not possible to keep the load at this maximum value; moreover, as the stressing frame was of rather limited capacity for large strains, the test could not be carried to fracture, although a total extension of 1.211 in. was obtained. The observance also showed that the permanent extension was very uniform from section to section.

The condition of the material had in fact some resemblance to that of a mild steel which has been over-strained and allowed to rest. This was shown by a subsequent experiment in which the loading was repeated and the stress-strain properties examined anew. It was then found that the elastic limit of the material was still approximately at 150-lb. load, corresponding to a stress of 1900 lbs. per sq. in., but the modulus E had now risen to 502,000, measured in pound and inch units, as a result of the overstrain. The relations of load to extension for both conditions are shown in Fig. 2, but as the scales of load and extension are the same for both experiments the curve for overstrained material lies below that for unstrained material. It may be observed that the material possesses, in a marked degree, the property of contraction when the load is removed even when very much overstrained, and in this case when the load of 300 lbs. was removed the semi-permanent extension was only 0.006 in., and half of this disappeared with a few minutes rest.

Observations of lateral strain were also made with a suitable extensometer at several sections of the test bar, and their mean value for 100-lb. load showed a strain of 0.00144, corresponding to a value of $m = \frac{1}{\sigma} = 2.45$ where σ is Poisson's ratio.

The value of E is high as later experiments showed and this may possibly be due to an aging effect, as in process of time the material appears to undergo some change, especially if the cut surfaces are not highly polished. This may probably be ascribed to the escape of a small portion of the volatile constituent of the material. It is also worthy of remark that the usual method of polishing appears to produce a thin outer layer which is harder than the interior, and this also has the effect of raising the value of E in thin specimens.

The effect of removing this thin layer of hard material has been under observation for some time, but in the experiments described here the flat sides were untouched, and the cut edges were unpolished although quite smooth.

Optical Properties.—There is considerable color when an overstrained specimen is examined under no load in the polariscope. In the parallel part the color is very uniform, and by comparing this with a previously unstrained specimen under load it appears that the permanent color indicates a complex state of stress, since it could not be completely neutralized by a comparison tension piece nor by bending the strained bar itself.

It may also be noted that nitro-cellulose with good optical properties is not easily procurable above ¼ in. thick, and it is difficult therefore to conform to the laws of similarity for the test specimens which were used in this investigation.

In later experiments the stress-strain properties of the material were examined both below and above the elastic limit, and the values of Young's modulus and Poisson's ratio were measured for a number of specimens of different thickness and varying age. Especial attention was also directed to the validity of the stress-optical law of this material since this is a matter of fundamental importance and little attention had been given to it.

Stress Optical Determination.—It was originally intended to study the stress-optical properties of nitro-cellulose by analyzing the light which traversed the material by means of a spectroscope; but the necessary apparatus was rather difficult to procure at the time, and it was convenient therefore to commence with a standard nitro-cellulose beam and use this for comparison with the optical phenomena observed in tension. The methods adopted here proved to be exceedingly well adapted for measurement of stress distribution beyond the elastic limit and are likely to be of considerable use hereafter. The comparison beam used was of rectangular section and was subjected to pure bending moment of known amount, and the stress at any point could therefore be calculated from the formula without appreciable error.

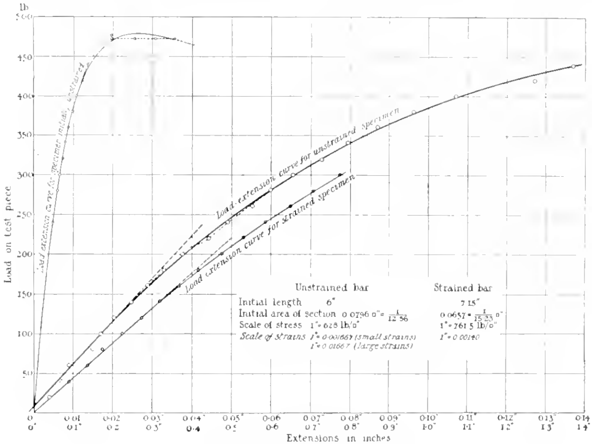

Fig. 2. Load-extension Diagrams

It is generally assumed that the relative retardation of the polarized rays in a piece of optical material under moderate stress is proportional to the difference of principal stresses at the point, but this may not be correct and cannot be assumed to hold without experimental proof. Hence the stresses in the comparison beam were restricted to small values, so that the limit of proportionality of stress to strain was not passed, in order to give an opportunity of examining the possibility of the law following a linear strain function or possibly some more complex variable. In order to make the retard-

[illegible] great to [illegible] highly stressed [illegible] the beam should [illegible] conveniently ob- [illegible] several beams side by [illegible] clamped and pinned [illegible] Fig. 3, in which several [illegible] together by plates [illegible] on levers *B* are also [illegible] loads *C* depending. This compound beam was [illegible] edges two inches apart. [illegible] had its central section [illegible] from the supports to give pure bending moment at the central section. The material of the beams was almost perfectly elastic up to and probably beyond 1600 lb. in.^{2}, but they were actually not stressed to more than 1300 lb. in.^{2} In some cases as many as eight beams 1/4 in. thick were used in this way, and a strong beam of light was then necessary to enable a comparison to be made with the tension member under observation. A carbon was then used as the source of light, but when only two or three thicknesses were employed the light from a Nernst lamp was sufficient. [illegible] in all cases the images were observed [illegible] instead of being projected on a screen. The general arrangement of the apparatus is shown in Fig. 4, in which a plane polarized beam of white light from a Nicol's prism *A* is transmitted through the tension specimen *B*, to which an extensometer *C* is secured, and is then focussed by a lens *D* on a horizontal slit in order that the light passing through the comparison beams shall be at the same level throughout. This thin pencil of light is again brought to parallelism before passing through the compound beam *F* and analyzer *G*, and is finally focussed on a ruled glass slide *H* provided with an eye-piece *J*. The weight of the extension beams and hangers caused a bending moment in the beams which was allowed for in all calculations of stress. In order to compare the different specimens one with another, an "equivalent stress" in each specimen was calculated, that is, such a stress as would produce the same relative retardation in a piece of nitro-cellulose of the same material as the standard beam, but of the thickness of the specimen under observation. Thus if the thickness of specimen is t and the stress in the beam at the points where the color in the specimen is neutralized is f_b and the corresponding thickness is t_b we have the equivalent stress in the specimen $f_b t_b / t$.

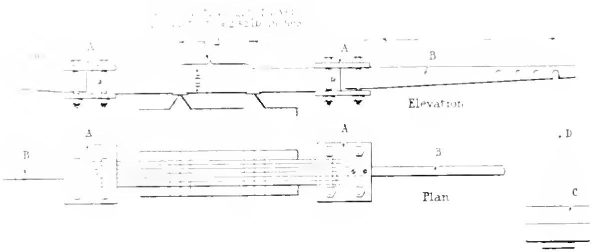

Fig. 3. Beam Comparator

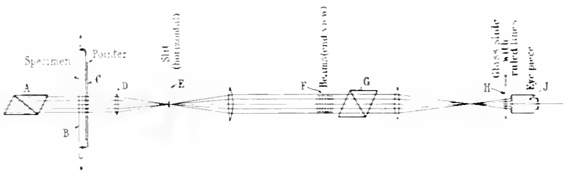

Fig. 4. Diagram of Polariscope

Now if M is the bending moment in the beam, d is its depth, and y is the distance from the neutral axis, then

$$f_o = \frac{My}{I} = \frac{12My}{t_o d^3}$$

so that the equivalent stress

$$f = \frac{f_o t_o}{t} = \frac{12\,My}{td^3}$$

Although as previously stated the law of optical retardation is generally assumed to follow a linear law of stress difference, yet there is no apparent reason why it should not follow some other law, as for example a linear strain law, or possibly contain terms involving squares of stress or strain. Some attempt was made to find if the latter assumptions had any foundation, but if so the effects were within the limit of experimental error, and too small to be of any significance with the effect produced by a linear relation.

As regards the question whether this relation should be expressed in terms of stress or strain, it may be pointed out that an attempt was made to test this with materials under direct stress, and that the validity of the law for combined stresses and strains still remains for consideration (apart from lateral strains, which are presumed to have no effect beyond altering the length of the path in which retardation takes place), but as in this case, if the standard, not stressed beyond the elastic limit, is compared with another in which this condition is passed the experiments do in fact provide a means of discrimination, since in the standard, stress and strain were proportional, but were not so, in general, for the tension member. Hence if the form of the law of optical effect is assumed in terms of stress it does not exclude the possibility of finding from the experimental evidence whether it should not be expressed in terms of strain. We may, therefore, without loss of generality, take as an assumption the usual relation that relative retardation $R = C(P-Q)T$ as a convenient expression where $(P-Q)$ is the difference of principal stress $=f$, T is the thickness of the material and C is the stress-optical coefficient.

Let C_o be the stress-optical coefficient of the standard beam. Then $R_o = C_o f_o t_o$ for this beam.

When this latter is used to neutralize the retardation R in the specimen, since $R = R_o$ we have

$$Cft = C_o f_o t_o$$

But $t = t_o$ here and therefore

$$Cf = C_o f_o$$

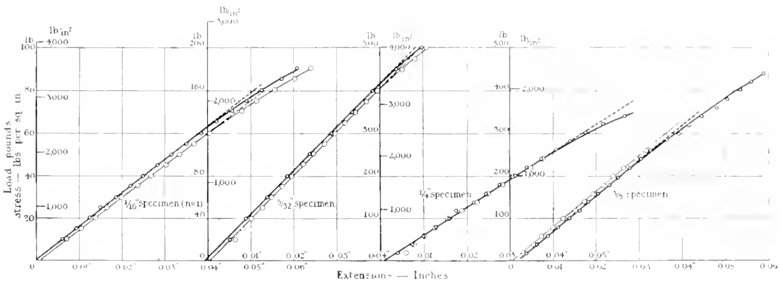

Fig 5

Now in general there is an initial retardation which is independent of any load. Let this correspond to stresses F, F_o. Then the condition $Cf = Cf_o$ becomes

$$C(f+F) = C_o(f_o+F_o)$$

or differentiating,

$$C \cdot df = C_o \cdot df_o$$

therefore

$$\frac{C}{C_o} = \frac{df_o}{df} = \text{reciprocal of slope of the stress equivalent stress,}$$

which afforded a convenient relation for examining the experimental data.

Turning now to the further experimental data upon the stress-strain properties of nitro-cellulose in tension, a number of experiments were made upon material of varying age and thickness, and these are plotted in Fig. 5, to show their characteristic properties under loads which sometimes exceeded the elastic limits of the material very considerably.

Wi[illegible] $\frac{1}{16}$ in. thick it was [illegible] obtain a reliable val[illegible] but Young's modulus [illegible] and the measurements [illegible] 5 [illegible] a characteristic feature [illegible] the first test was carried well [illegible] range, as soon as the load [illegible] a total extension of 0.0608 in. [illegible] reduced to 0.0070 in., or only 0.001 in. more than obtained at the commencement of the test. Moreover the value of the modulus changed less than 2 per cent under these circumstances due to the earlier loading. It was also large as the skin effect was pronounced. These general characteristics were also observable in the measurements recorded in this figure for much thicker material when due allowance was made for the diminished effect of the surface layers. The capacity of returning to its original shape after high loads was still more marked in the next series of experiments on material $\frac{1}{8}$ in. thick, Fig. 6, in which a stress of nearly 5000 lbs. per sq. in. was reached in the first experiment (curve 1) with nearly complete recovery, and when further loads with maxima varying from 4000 to 5000 lbs. per sq. in. were applied (curves 2 to 8) these gave almost identical values of Young's modulus on the straight part of the curve until the ninth loading, where there was a sudden fall to $E=261{,}000$ with an extension of 0.1045 in. corresponding to the initial load of 20 lbs. After this, with the considerable initial extension of 0.4290 in., there was a great rise in the modulus. The value of Poisson's ratio was very constant in this experiment.

Succeeding experiments on still thicker material confirmed these results, and with the exception of the $\frac{3}{8}$-in. plate, the load extension curves agreed in their linear character up to about 2000 lbs. per sq. in., although the specimens differed in age and possibly also in composition. They had, however, the common feature of possessing excellent optical properties and freedom from initial stress. The thickest plate, however, was exceptional, as its optical properties were poor.

Further experimental work on these materials was almost entirely devoted to the examination of the optical law of retardation under load, and for convenience all the data which follows are expressed as a stress or a strain, the units being pounds and inches, in which e is the strain under direct stress f, and the equivalent stress f_o is obtained from the comparator beam. A typical example of these values is given in Table I, for material $\frac{1}{4}$ in. thick, as these measurements are referred to later for comparison with values of stress and strain obtained from spectrum observations.

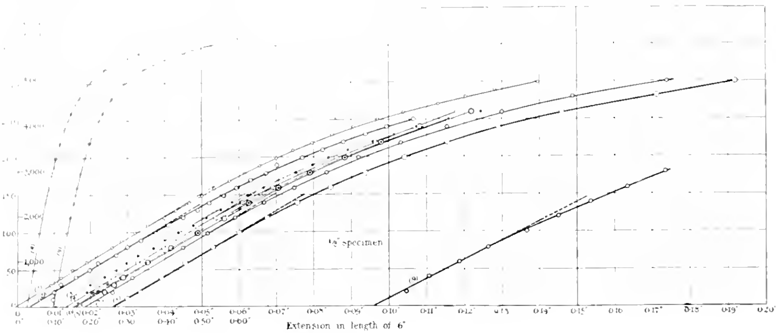

Fig. 6. Load-extension Diagram (Low Stresses)

In the earlier experiment on the material $\frac{1}{16}$ in. thick, a fracture was obtained near the change of section and before the full extension developed, but still very nearly at the full load. It is included here (Fig. 7), for although the later parts of the stress-strain curves are not entirely satisfactory, this fact does not affect the problem in hand, since the stress-strain curve is not required very much beyond a pronounced yield in the material.

As a purely mechanical problem, however, there is a considerable amount of interest attaching to the accurate measurement of stress and strain over the whole of the plastic region, and it may be worth while at some future time to examine this with some care, especially if optical methods are applied to study the distribution of stress in purely plastic materials.

Fortunately the means for carrying this out are at hand since the autographic testing machine of my university colleague Prof. Dalby, F.R.S., enables very accurate stress-strain diagrams to be obtained throughout the whole range of stress to fracture under the most varied conditions. In this apparatus the load is measured by the elastic extension of a tension member placed in series with the specimen under test, and both stress and strain are recorded automatically on a photographic plate by the movement of a spot of light, which latter is reflected from tilting mirrors with axes at right angles.

The stress-strain curves obtained for thin material showed a divergence from a linear law above 2000 lbs. per sq. in. whether plotted from the direct load or the optical stress measurements, but if the direct stress is plotted against its optical equivalent there is a definite linear law extending up to at least 4500 lbs. per sq. in., and with only a small divergence at 5000 lbs. per sq. in. The results in fact showed that the law of retardation is linear as regards stress, not only up to the elastic limit but actually to at least twice this range, where it is quite impossible for the strain to be linear. This result is shown in all the experiments on good optical material.

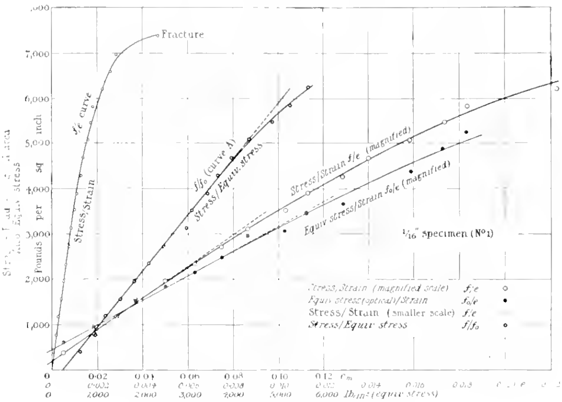

Fig. 7. Stress-strain Curves of Nitro-cellulose

Thus in plates 1/8 in. thick where the elastic limit appears to be about 2250 lbs. per sq. in., Fig. 8, the corresponding value for

TABLE 1

NITRO-CELLULOSE, VALUES OF SHEET 1/4-INCH THICK STRAIN e, STRESS f AND EQUIVALENT STRESS f_0

e	f	f_0	e	f	f_0
0	0	73	0.0123	3345	3440
0.0003	160	220	0.0135	3505	3560
0.0007	319	322	0.0142	3665	3900
0.0013	478	440	0.0153	3825	4140
0.0020	637	660	0.0172	3980	4500
0.0027	797	880	0.0187	4140	4770
0.0033	956	1025	0.0208	4300	5100
0.0037	1115	1173	0.0212	4460	
0.0043	1274	1320	0.0237	4620	
0.0050	1433	1495	0.0287	4780	
0.0055	1594	1642	0.0320	4940	
0.0058	1752	1760	0.0370	5100	
0.0063	1912	1910	0.0553	5260	
0.0070	2070	2050	0.120	5420	
0.0077	2230	2200	0.157	5580	
0.0082	2390	2350	0.183	5740	
0.0087	2550	2540	0.247	5900	
0.0095	2710	2310	0.280	6055	
0.0102	2865	2860	0.340	6215	
0.0108	3025	3080	0.357	6375	
0.0117	3185	3230			

... from linearity until ... unt, although the ... be linear at about ...

... ilar results were obtained on ... thick, but in both experiments, ... of f/e had a rather higher ... limit than the corresponding f/e curve; have corresponding limits of 2000 lbs. per sq. in.

When these curves were corrected for the change of cross-section which occurred as the test proceeded it was found, as Fig. 11 shows, that the stress-strain curve was perceptibly raised beyond the elastic limit and therefore tended more towards linearity, and the

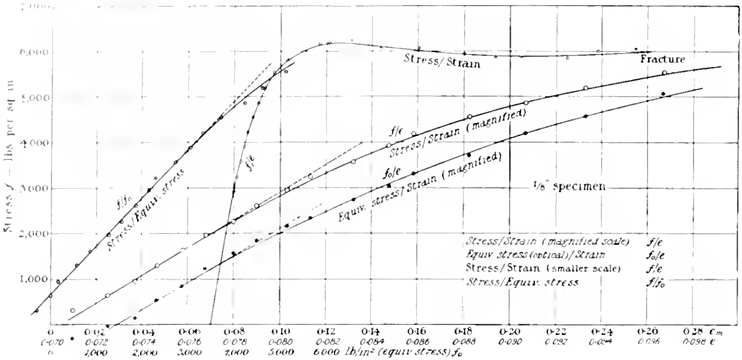

Fig. 8

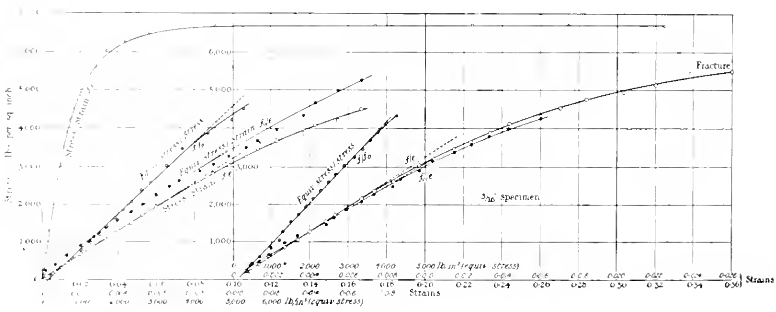

Fig. 9

but here again the ratio f/f_0 was still linear to about the same range as in previous cases.

The case of plates 1/4 in. thick, Fig. 10, is more especially interesting from the fact that the stress-strain curve there shown was, at a later stage, obtained entirely from the optical effects observed from the analysis of the spectrum of a beam under uniform bending moment. It is sufficient to remark here that the f/f_0 curve shows a somewhat lower limit of linearity, although both the other curves equivalent stress strain curve was lowered and diverged still more from the linear relation. The stress equivalent-stress curve has therefore a somewhat higher linear limit when this correction is made. Owing to the defective optical properties of still thicker material it was not found possible to examine these relations in a 3/8-in. plate in a satisfactory manner.

Fracture.—The behavior of nitro-cellulose at fracture is somewhat unusual for so ductile a material. As the load increases the section diminishes very uniformly at all parts removed from the enlarged ends, but there is little or no local contraction at any stage, and even at the fractured section the cross-section differs but little from that at any other part of the bar; but after fracture there is a remarkable contraction in the total length accompanied by uniform expansion of the cross-section. This is shown in Table II, which gives a summary of the observations made, and except for one of the thin specimens and for the reasons given earlier there is shown a recovery in length of from 6 to 9 per cent after fracture. Various other measurements already described above are recorded here for convenient reference and also some ratios of the optical constants.

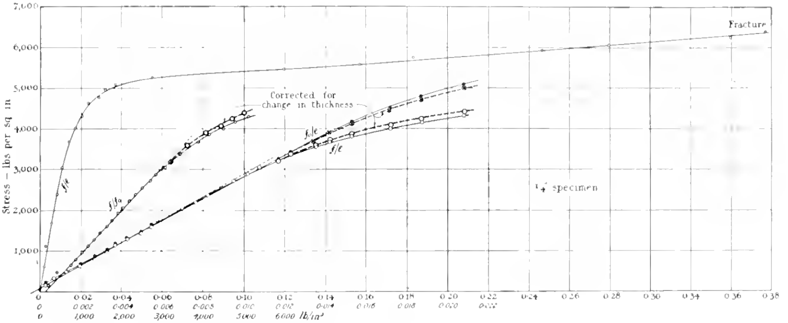

Fig 10

TABLE II

PROPERTIES OF NITRO-CELLULOSE IN TENSION, TEST LENGTH 6 INCHES

Specimen	$\frac{1}{16}$" (No. 1)	$\frac{1}{16}$" (No. 2)	$\frac{1}{8}$"	$\frac{5}{32}$"	$\frac{3}{16}$"	$\frac{1}{4}$"	$\frac{3}{8}$"
Width	0.5086	0.5090	0.5050	0.4992	0.4978	0.4972	0.4992
Thickness	0.0505	0.0506	0.1213	0.1517	0.1863	0.2533	0.4045
Area (in.²)	0.0257	0.0258	0.0613	0.07575	0.0928	0.1258	0.202
Modulus $\frac{\text{lb.}}{(\text{in.}^2)}$	362,000	355,000	295,000	324,000	313,000	309,000	251,000
Poisson's Ratio	.	. .	2.7	2.5	2.6	2.3	2.4
$\frac{C}{C_0}$ (optical)	0.82	0.84	0.97	1.00	1.00	0.95	1.20
Maximum extension before fracture (in.)	0.28	1.66	1.53	2.14	1.94	2.14	2.26
Ultimate extension after fracture (in.)	0	1.23	1.07	1.67	1.54	1.72	1.74
Recovery in length (in.)	0.28	0.43	0.46	0.47	0.40	0.42	0.52

Spectrum Analysis of the Stress in a Beam.—The results of the optical examination appeared to show the truth of the optical stress law for simple stress well beyond the elastic limit of the material, but the importance of this fundamental law made it desirable to examine the matter in an independent way and possibly by a more rigid test than a comparison beam afforded. An investigation of the optical phenomena presented by a beam under pure bending moment was therefore made on a rectangular strip 22½ in. long, 1.005 in. deep, and 0.2542 in. thick. Its specific gravity was approximately 1.361, being determined at a temperature of 64 deg. Fahr. by measurement of its volume and weighing in air.

The beam was supported as before on knife edges 2 in. apart, and the loading was applied at each end by dead weights having an overhang of 9¾ in.

The optical arrangements were also modified for the new conditions as shown in Fig. 11. Light from the filament *A* of a Nernst lan[illegible] to a vertical slit S by aid[illegible] ing through a Nicol's [illegible] narrow band was in turn [illegible] ral section of the beam [illegible] ed by a second Nicol's prism [illegible] placed at a convenient distance

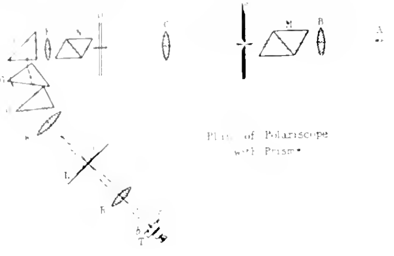

Fig. 11

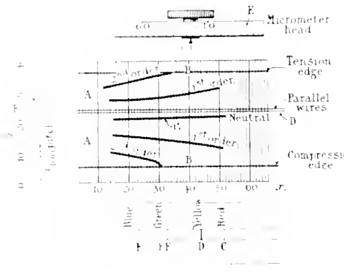

Fig. 12. View of Spectrum

from the beam transmitted this light as a parallel beam to a reflecting prism F, from which it passed through prisms G, H. The spectrum so obtained was focussed on a glass screen L ruled with lines 1/100 in. apart, and provided with a micrometer eye-piece for measuring the ordinates of the bands observed.

The field of view therefore consisted of the spectrum of a Nernst lamp filament to which was added the effect produced by a narrow section of a beam of rectangular cross-section under pure bending moment. The relative retardation, owing to this latter stress effect, produced black bands in the field having a variable distance apart, depending on the optical law of the retardation of the wave-length.

The general disposition of the field of view [illegible] in Fig. 12, in which bands of the first and second order appear on each side of the neutral axis C of the beam, and their co-ordinates were measured by reference to the graduations on the glass scale with the aid of a pair of parallel wires D, the positions of which could be adjusted vertically by a micrometer head E reading to 1/6000 in., while complete turns of the screw were obtained from a scale F on the left, which also appeared in the field of view. In order to calibrate the horizontal scale the Nernst lamp and nitro-cellulose beam were removed, the Nichol's rotated to parallelism, and a beam of solar light focussed on to the slit. The position of lines of known wave-length were noted with reference to the horizontal scale, and from these observations the constants in the equation

$$x_1 = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$$

were found for calibrating the positions of the black bands.

In the observations it is found that the depth of the beam did not appear quite constant throughout the field, an error due to the combined imperfections of the lenses and prisms employed. The maximum change of depth was about 2 per cent and a correction was therefore necessary to reduce all vertical distances to a constant depth of beam.

Owing to the presence of a small amount of initial retardation in plates of nitro-cellulose, due to the method of manufacture, which leaves traces of initial stress, there was generally some slight difference between the bands on each side of the neutral axis, and a

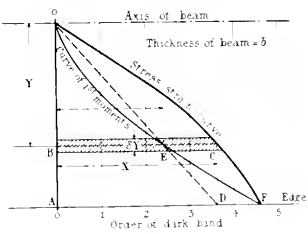

Fig. 13

more accurate value is probable if the mean value for the two sides are taken, as was done here.

If relative retardation is a linear function of the stress difference, these new abscissae should represent the mean stress, but if the strain varies linearly they should also represent strains to another scale.

If then the mean distances of the bands are plotted as ordinates against the order of the band as abscissae, Fig. 13, a convenient form of diagram OCF is obtained in rectangular co-ordinates X, Y, in which Y is the distance from the neutral axis to a scale α, and f is the stress to a scale β, or

$$y = Y\alpha \quad f = X\beta$$

Now the bending moment

$$M = \int_{-\frac{1}{2}d}^{+\frac{1}{2}d} f\,b\,y\,dy$$

for a breadth $= b$ and a depth $= d$, or

$$M = b\,\alpha^2\,\beta \int_{-\frac{1}{2}d}^{+\frac{1}{2}d} X\,Y\,dY$$

$= 2\,\alpha^2\,\beta\,b$ times the first moment of the area of the diagram about the neutral axis.

If now any point C on the curve is projected on to the edge line at D and line OD

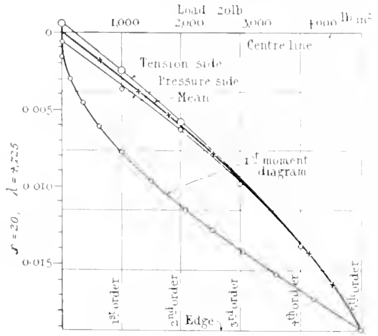

Fig. 14. Stress-strain Curves

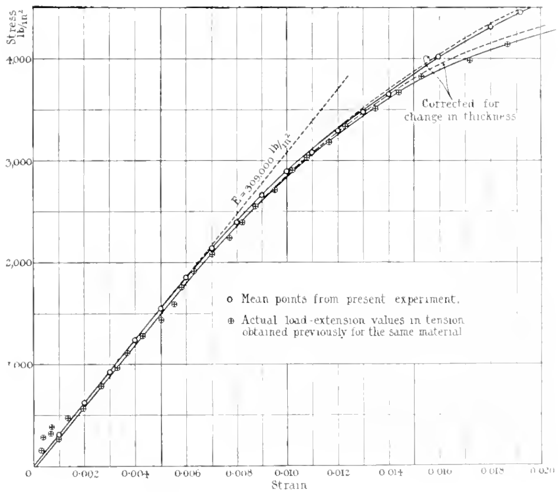

Fig. 15. Comparison of Stress-strain Curves

is drawn to the origin of co-ordinates intersecting the horizontal through C at E, then

$$BE : Y :: AD : AO = X : \frac{d}{2}$$

or

$$X\,Y = BE \times \frac{d}{2}$$

Hence, $\int_{-\frac{1}{2}d}^{+\frac{1}{2}d} X\,Y\,dY$ represents the area $OEFAO \times d$. A typical example of one of these diagrams is shown in the curves of Fig. 14, of which about 40 were actually prepared. The first moment areas M', as determined by planimeter measurements, were divided by the bending moment to obtain a value of $\alpha^2\,\beta b$. If, however, the relative retardation is assumed to be independent of the wave-length, the mean value of $\frac{M^1\lambda}{M}$ affords values of β corresponding to dif-

TABLE III

Strains	0.001	0.002	0.003	0.004	0.005	0.006	0.007
Stresses in lbs. per sq. in.	310	620	920	1240	1540	1845	2135
Strains	0.008	0.009	0.010	0.011	0.012	0.013	0.014
Stresses in lbs. per sq. in.	2400	2665	2890	3055	3285	3460	3680
Strains.	0.018	0.0192					
Stresses in lbs. per sq. in	4310	4455					

[illegible] the values of β were [illegible]

[illegible] the scale of strains [illegible] modulus $E = 309,000$, [illegible] measurements in tension [illegible] it, and assumed to hold [illegible] of the beam for all loads. [illegible] we have the strain $e =$ [illegible] the scale for strains, then

$$\frac{dt}{de} = \frac{\beta}{s} \cdot \frac{dX}{dY}$$

[illegible]

$$= \frac{\beta}{E} \cdot \frac{dX}{dY}$$

The slopes $\frac{dX}{dY}$ near the neutral axis were measured from the diagrams similar to those of Fig. 14, and their mean values afforded measures of the strains.

The data obtained by this method were therefore sufficient to construct a stress-strain curve entirely from measurements of the bands due to retardation in the spectrum, and if the assumptions are correct, it ought to agree with a similar diagram constructed from data obtained independently. The stress-strain diagram obtained from spectrum observations gave, in fact, the values of stress and strain shown in Table II, but this information has already been obtained by observations on precisely similar material under direct tension stress, Table I and Fig. 9, and on comparing plots of the two sets of data obtained, Fig. 15, the agreement is seen to be a remarkably close one up to about 3500 lbs. per sq. in. This agreement is improved if the changes in thickness are allowed for, since the corrected curves then lie closer together and strengthen the evidence in favor of the law of optical retardation being an effect of stress and not of strain, and also that it is still a linear function much beyond the elastic limit of the material.

The whole of the evidence, in fact, appears to show that the transparent nitro-cellulose examined obeys a linear stress optical law which holds up to approximately twice the range of the elastic limit of stress; and that within this range optical determinations of stress distribution may be relied upon.

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Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Bearings

High-Temperature Properties of White-Metal Bearing Alloys. Freeman, Jr., John R. and Woodward, R. W.
Soc. Auto. Engrs. Jour., Feb., 1921; v. 8, pp. 149-154, 162.
(Technical paper.)

Circuit Breakers

Present-Day Practise Limitations of Oil Circuit Breakers. Woodrow, H. R.
A.I.E.E. Jour., Mar., 1921; v. 40, pp. 198-200.
(By the Sub-Committee on Oil Circuit Breakers and Switches of the Protective Devices Committee, A.I.E.E.)

Converters, Synchronous

Developments in Conversion Apparatus for Edison Systems. Barton, T. F. and Hambleton, T. T.
A.I.E.E. Jour., Mar., 1921; v. 40, pp. 233-243.

Cranes, Electric

Bergmann System of Motor Control for Lifting in Electric Crane Installations. Blau, Ernst. (In German.)
Elek. und Masch., Jan. 16, 1921; v. 39, pp. 29-31.
(A modification of the Leonard system.)

Electric Current Rectifiers

Brown-Boveri Mercury Arc Rectifier for Large Outputs. Morrison, R. L.
Elec. Rev. (Lond.), Feb. 18, 1921; v. 88, pp. 217-219.
(Explains construction and operation. Serial.)

Electric Meters

Standard Voltmeter for 250,000 Volts Effective Pressure. (In German.)
Elek. und Masch., Jan. 16, 1921; v. 39, pp. 37-38.
(New apparatus developed by Hartmann & Braun Company.)

Electric Motors, Induction

Number of Bars and the Torque of Short Circuited Armatures. Stiel, W. (In German.)
Zeit. des Ver. Deut. Ing., Feb. 5, 1921; v. 65, pp. 147-152.
(Results of an extensive investigation of a Siemens-Schuckert induction motor. Eleven rotors were used in which the number of bars was varied.)

Story of the Induction Motor. Lamme, B. G.
A.I.E.E. Jour., Mar., 1921; v. 40, pp. 203-223.
(Chief Engineer of the W. E. & M. Co. gives the history of the technical development of the induction motor.)

Electric Transformers, Instrument Type

Errors Arising in Measuring Output with Instrument Transformers. Goldstein, Dr. J. (In German.)
Schweiz. Elek. Ver. Bul., Jan., 1921; v. 12, pp. 14-16.
(Supplements a longer article published in November, 1920, issue of same paper.)

Electric Wave Form

Magnetic Circuit and the E.M.F. Wave-Form of an Alternator. Champney, L.
Beama, Feb., 1921; v. 8, pp. 147-152.
(Technical paper. Serial.)

Electrical Machinery—Temperature

Longitudinal and Transverse Heat Flow in Slot-Wound Armature Coils. Fechheimer, Carl J.
A.I.E.E. Jour., Mar., 1921; v. 40, pp. 244-248.
(Serial article by a Westinghouse engineer.)

Electricity—Applications—Domestic

Thermal Characteristics of Electric Ovens and Hot Plates.
Engr. (Lond.), Feb. 18, 1921; v. 131, pp. 176-177.
(Presents test results as shown in a paper by Griffiths and Schofield before I. E. E.)

Electromagnets

Calculation of Direct-Current Electromagnets. Gábor, Eugen. (In German.)
Schweiz. Elek. Ver. Bul., Jan., 1921; v. 12, pp. 1-14.
(Lengthy article, with curves and two tables showing the electrical constants of American and German wire.)

Factory Lighting

Illumination Design Simplified. Anderson, Earl A.
Elec. Wld., Feb. 19, 1921; v. 77, pp. 417-422.
(Extensive data for the calculation of industrial lighting.)

Fatigue of Metals

Relation of Recoverance to the Fatigue of Metals. Guthrie, Robert G.
Soc. Auto. Engrs. Jour., Jan., 1921; v. 8, pp. 65-68.
(Short, illustrated paper of technical nature.)

Generating Sets

Present Status of the Isolated Gas-Electric Generating Plant. Froesch, Charles.
Soc. Auto. Engrs. Jour., Jan., 1921; v. 8, pp. 28-42.
(Well-illustrated article on various types.)

Hydr[illegible]

[illegible] 15 Months. Starr, R. C.
[illegible] 26, 1921; v. 77, pp. 471-474.
[illegible] description of the Kerck[illegible]nt of the San Joaquin Light [illegible] Corporation.

Inductance

[illegible] Two Cases of Asymmetrical [illegible] Systems. Hak, J. (In German.)
[illegible], Jan. 23, 1921; v. 39, pp. 41-42.
Graphical treatment of induction phenomena.

Inductive Interference

Inductive Interference Due to Single-Phase Electric Railroads. (In German.)
Elek. Kraft. und Bahnen, Feb. 10, 1921; v. 19, pp. 28-32.
Review of a Swedish report.

Insulation

Effect of Heat on Paper Insulation. Fisher, H. W. and Atkinson, R. W.
A.I.E.E. Jour., Mar., 1921; v. 40, pp. 183-191.

Higher Temperatures in Cable Insulation.
Elec. Wld., Feb. 19, 1921; v. 77, pp. 413-415.
(Results of tests.)

Permissible Operating Temperatures of Impregnated Paper Insulation in Which the Dielectric Stress is Low. Roper, D. W.
A.I.E.E. Jour., Mar., 1921; v. 40, pp. 201-202.

Insulators

Distribution of Voltage Over Suspension Insulators. Dachary, Ch. and Goree, P. de la. (In French.)
Soc. Fr. des Elec. Bul., Nov., 1920; v. 10, pp. 345-362.
(Lengthy technical paper with tables and graphs.)

Power Factor

Use of Over-Excited Synchronous Motors for the Improvement of Power Factor and for Voltage Regulation. Martin, Rene. (In French.)
Revue Gén. de l'Elec., Feb. 12, 1921; v. 9, pp. 205-211.
(Theoretical.)

Radio Direction-Finding

Errors of Direction-Finders. Bellini, Dr. E.
Elec'n. (Lond.), Feb. 18, 1921; v. 86, pp. 220-222.

Radiotelegraphy

Heterodyne System of Wireless Reception; Its Advantages and Future. (In French.)
Soc. Fr. des Elec. Bul., Nov., 1920; v. 10, pp. 363-374.
(Technical in part.)

Recent Progress in Wireless Telegraphy. Abraham, Henri and Bloch, Eugene. (In French.)
Soc. Fr. des Elec. Bul., Nov. 1920; v. 10, pp. 387-395.
(Concerned particularly with methods of graphically recording radio messages.)

Signalling, Submarine

"Leader" Cable at Portsmouth. Bennett, J. J.
Engng. (Lond.), Feb. 18, 1921; v. 111, pp. 187-190.
(Illustrated article on the principles of guiding ships by means of radiations received [illegible] along the course.)

Steam Turbines

Steam Turbine Losses Due to Residual Steam Speed. (In French.)
Revue BBC, Oct., 1920; v. 7, pp. 251-263.
(Theoretical article on losses due to residual kinetic energy in the steam leaving the last stage.)

Vibrations of Steam Turbine Blades; Influence of Centrifugal Force on the Natural Period. (In French.)
Revue BBC, Oct., 1920; v. 7, pp. 267-272.
(Theoretical.)

Thrust Bearings

Krupp's Single Collar Thrust Bearings.
Tech. Rev., Feb. 15, 1921; v. 8, p. 156.
(Short, abstract translation of article in "Krupp'che Monatshefte" and in "Zeit. des Ver. Deut. Ing.," Oct. 30, 1920.)

Turbo-Generators

Breakdown of Turbo-Alternator Plant at Glasgow.
Engng. (Lond.), Feb. 18, 1921; v. 111, p. 198.
(Brief account of failure of a 15,000-kw. Metropolitan-Vickers machine at Dalmarnock Stations, Glasgow, Scotland.)

X-Rays

X-Ray Examination of Materials. Clarke, J. R.
Beama, Feb., 1921; v. 8, pp. 125-132.
(General article on practical uses of the X-ray.)

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Elementary Dynamics; a Text-Book for Engineers. Landon, J. W. 246 pp., 1920, Cambridge, University Press.

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National Electrical Safety Code.—A third edition of the National Electrical Safety Code prepared by the Bureau of Standards, Department of Commerce, Washington, has been issued and is known as Handbook No. 3 of the Bureau of Standards.

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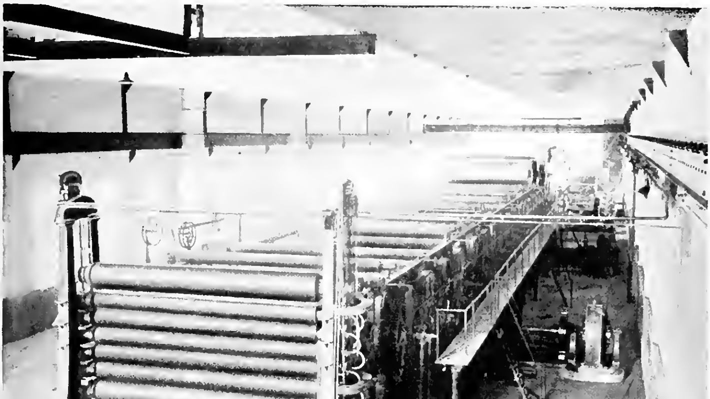

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INDUSTRIAL POWER LOADS

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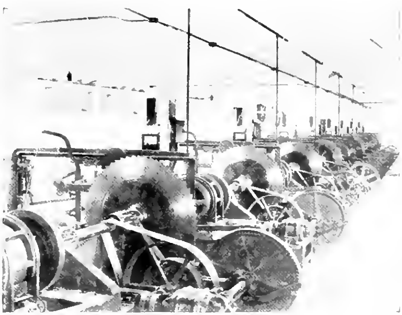

INDUSTRIAL POWER LOADS

General Electric Review

A MONTHLY MAGAZINE FOR ENGINEERS

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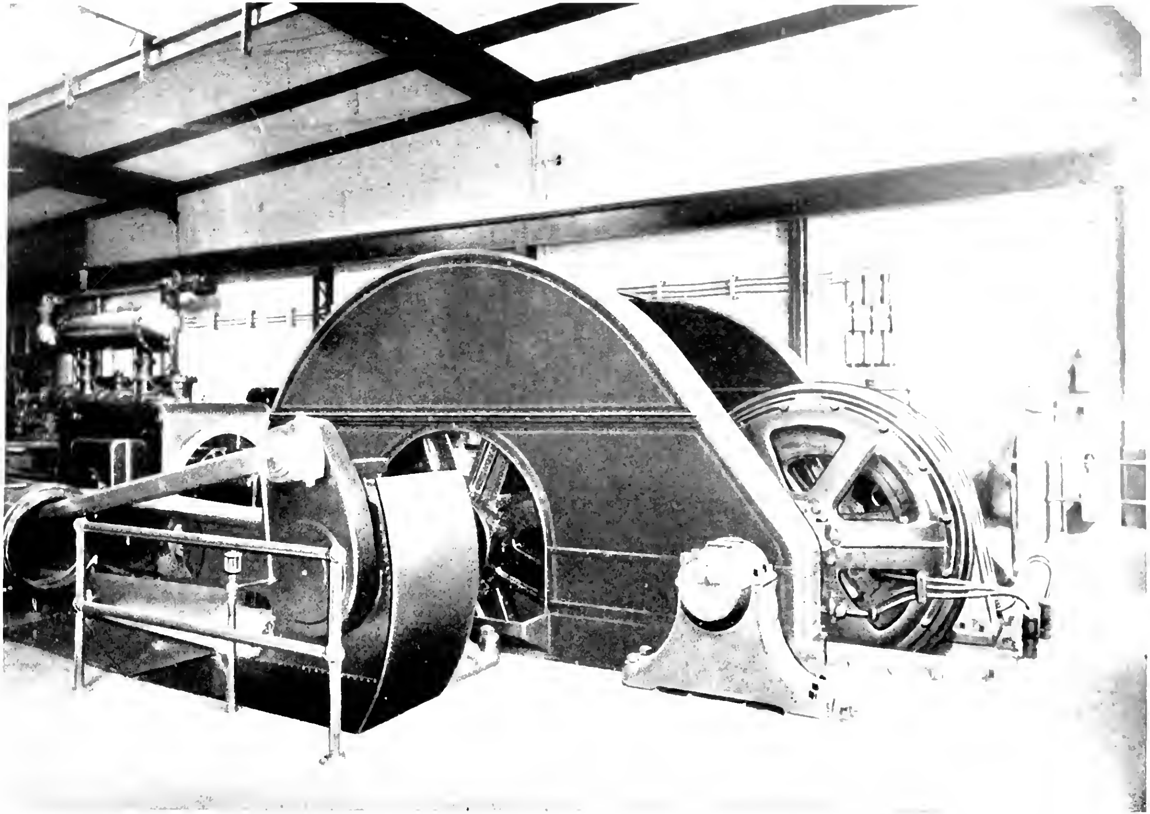


800-h.p. Induction Motor Geared to a Pump Originally Operated by Steam Power. Big Hole Pumping Station of the Butte Water Company, Devide, Montana. This installation is a striking example of the preference that is everywhere being shown for electric drive. Aside from the simplicity, cleanliness, convenience, and freedom from trouble of the electric motor, the matter of economy is largely responsible for its popularity

GENERAL ELECTRIC REVIEW

THE GROWTH OF THE INDUSTRIAL POWER LOAD

The central station industry was born of the attempt to furnish electricity over a small but scattered area for the lighting of streets and buildings with the carbon open arc and the carbon incandescent lamp. In the earlier years, with the cumbersome generating equipment then available, this load was regarded as considerable; in fact, the demand for electric lighting must have consistently exceeded the capacity to judge from the increase in size and number of stations that marked a single year's progress.

The principal objection to this business was the fact that it was all peak load, coming on in the evening and lasting for only a few hours. Most or all of the equipment lay idle during the day, and consequently the load factor over a 24-hour period was extremely low. This condition induced the lighting companies to look afield for other business which would keep their plants operating during the daytime. The manufacturing industries offered the greatest possibilities, where electric energy could provide motive power to replace the isolated steam engine installations that were then a part of every manufacturing establishment. We can readily imagine the persistence that was necessary in many cases to induce an owner of a steam operated mill to surplant his steam equipment with the electric motor; but when once the change was effected the advantages of the motor transcended all prejudice, and today the industrial motor load provides the principal revenue of the central station. The betterment of the load factor is pronounced, the station load curve coming up in the morning and continuing through the evening, except for a sharp dip at noon in most cases.

A survey of the industrial motor load served by central stations in this country as made by the *Electrical World* during the past six years gives some interesting facts. The last year for which figures are available is 1919, but the curves have been projected ahead to January 1, 1925.

The number of stationary motors served on January 1, 1915, was roughly 575,000; on January 1, 1920, the number had doubled. The estimated number of motors in service January 1, 1925, is approximately double the number on January 1, 1920—practically a uniform rate of increase over the ten-year period. The connected motor load for these years is about in proportion to the number of motors, being roughly 6,100,000 h.p. on January 1, 1915, 12,900,000 h.p. on January 1, 1920, and having an estimated value of 20,800,000 for January 1, 1925.

The figures for kilowatt-hours sold are specially significant, for they show that the central station load, which was originally 100 per cent lighting, was 34.5 per cent lighting in 1915 and only 28.4 per cent lighting in 1919. The energy sold to power customers (all classes) in these years was respectively 51.1 per cent and 57.2 per cent. These percentages include the energy delivered to street railways, which amounts to 13½ per cent of the total energy sold. Distribution losses are estimated to be 14.4 per cent.

Thus we see that the industries provide the dominant load of the central station, mostly in the form of motors but also to a considerable extent through the use of electric furnaces, industrial heating, and electrochemical processes. The nature of these several loads is as varied as the industries themselves, and in order to render satisfactory service to all comers, and at the same time to avoid undesirable load conditions which would interfere with service to other customers, central station engineers have found it necessary to make intensive study of industrial load characteristics. It is essentially the duty of the power salesman to know the possibilities for the extension of electric service to all classes of industry within his territory and to familiarize himself with their load cycles in order to be able to negotiate power contracts which at once will be attractive to his customer and profitable to his company.

The articles on industrial power loads in this issue of the GENERAL ELECTRIC REVIEW, which will be distributed coincident with the Chicago Convention of the National Electric Light Association, have been prepared at the request of the editors by a corps of experts for the express purpose of assisting central station men to a better understanding of some of the principal problems involved in supplying service to their major customers, the industries, and to stimulate more active interest in the possibilities of the industrial power load.

B. M. E.

THREE YEARS OPERATION AT WINDSOR

[illegible] in the operation of a lar[illegible] power station located at [illegible] the subject of an unusually [illegible] to this issue by Mr. [illegible] McFarland of the Beech Bottom Power Company. The power that is generated and [illegible] transmission lines releases for other purposes the continuous services of thirt[illegible] train crews and from five hundred to seven hundred coal cars. Thus a definite basis of experience is established for discussing superpower zones and superpower stations.

The turbine-generators are 30,000-kw., 1800-r.p.m. units of the standard single flow Curtis type supplied by the General Electric Company. The operating record at Windsor and elsewhere has established the fundamental soundness of the design and the great reliability, or stamina, to use Mr. McFarland's expression, inherent in these large turbines.

Mr. McFarland has summarized the records of operation in a table of "operation factors." These factors are in accordance with definitions suggested by the Prime Movers Committee of the N.E.L.A.

The "station generating factor" is a measure of the productive activity of the money invested in the enterprise. A high generating factor means a proportionately lower overhead charge. In central station practice a load factor around fifty per cent is regarded as good. The "generating factor" in part depends upon and must be lower than the load factor so that station generating factors of from sixty to sixty-six per cent for yearly operation must be regarded as establishing a new record for continuous driving of apparatus.

In considering the availability factor a clear distinction must be made in the use of the word operative. In order to insure as nearly as possible continuous operation it is necessary to do a certain amount of repair and maintenance work. That is, operative apparatus must be periodically shut down and inspected in order to make sure that it will continue to be in operative condition. Auxiliary apparatus must be overhauled, condenser tubes repacked, cleaned or replaced, generators cleaned and inspected, turbines inspected, and if necessary adjusted, etc. While the unit, consisting of all of the above apparatus, is shut down for such repair work to any of its elements, as a whole it has been regarded as inoperative, although up to the instant of shutdown the unit was operative and were it desirable could have been kept in operation.

In reference to certain industrial plants the statement will be made: "Our availability factor is 100 per cent. We run continuously day and night six days a week. Of course, we do a little maintenance work and make minor adjustments on Sunday, but the units could be run if we needed the load and they are available for service all of the time." Obviously this would not be considered an availability factor of 100 per cent in the meaning of the term employed by Mr. McFarland. Maintenance work should be done at the most convenient time, all things considered, and for Windsor at least Sunday is not different from Tuesday or any other day.

In a station with a load demand justifying the installation of four units the installation of a fifth unit might permit four units to be kept in continuous service, with one unit available for repair and maintenance work. This might be an ideal arrangement aside from first cost and would permit four units being kept in a highly tuned up condition all of the time. However, the station availability factor on this basis would be eighty per cent and the station generating factor would be low.

With these points in mind the average station availability factors obtained at Windsor are highly creditable.

The station load factor is virtually the ratio of the average load to the peak load and a high load factor does not necessarily mean good station performance. Units might operate steadily at fractional loads with a good load factor, but when the peak loads approximate the maximum capacity of the station a good load factor plus a good availability factor results in a good station generating factor, as at Windsor.

During the period covered by the table given in Mr. McFarland's paper three new units were installed and placed in service and the units were regarded as in commercial service from the time they were first placed on the line. It is well known that each piece of apparatus comprising a unit will require a certain amount of adjustment and tuning up in order to put it in first-class operating condition. With these facts in mind the records given in the article are remarkable and furnish a basis for interesting comparisons.

E. E. Gilbert

Industrial Power Loads

By D. B. Rushmore, Engineer, and R. F. Emerson
Power and Mining Engineering Department, General Electric Company

D. B. Rushmore

THE means of furnishing mechanical power to our industries is derived from three chief sources, namely, coal, water power and petroleum. The circular diagrams, Fig. 1, will give an idea of the quantity of each source of power in the U.S.A. and the amount which has been used up, or developed, within recent years.

The time to elapse before the total consumption of our coal supply has been variously estimated at from several hundred years up to several thousand years. A sector representing this country's requirements for one year (roughly estimated at 600,000,000 tons) would hardly show on the diagram 1a.

Fig. 1b shows that a considerable portion of our reserve of petroleum has been utilized; also that one year's requirements plus the steadily increasing demand will cause this supply of fuel to be exhausted in a relatively short time.

R. F. Emerson

Fig. 1c shows a source of power which is inexhaustible, but the estimated total of 59,360,000 horse power including storage will never be sufficient for supplying power to our industries and for other purposes. This becomes more apparent when we consider the increasing demand for power as shown by the primary horse-power curve in Fig. 6. Furthermore the bulk of

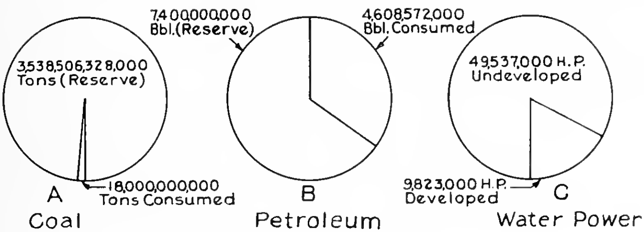


Fig. 1. The Three Chief Sources of Power

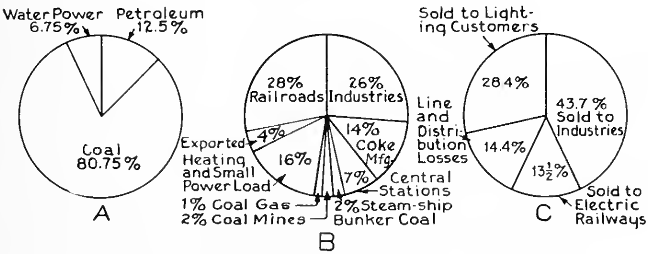


Fig. 2a. Relative Magnitude of the Three Sources of Power on a Fuel Basis
Fig. 2b. Distribution of Yearly Coal Production
Fig. 2c. Distribution of Central Station Power

... of the Mississippi ... demand for indus- ... Eastern States. ... sources of power to ... shown in Profes- ... before the 1920

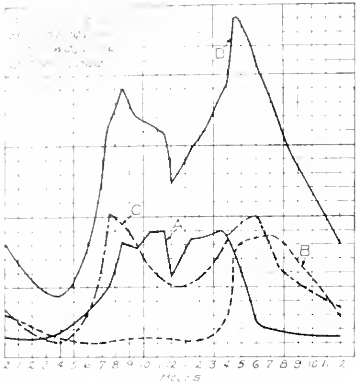


Fig. 3 Daily Load Curve of Central Station in Large City

annual meeting of the A.S.M.E., shows that a year's requirements of the United States for coal, petroleum and water power bear the relative importance to each other shown in Fig. 2a.

It is seen that coal is by far the most important of these three sources of power at the present time. From the data contained in the article by Prof. R. H. Fernald in the GENERAL ELECTRIC REVIEW for August, 1918, we can show that coal is used for various purposes in the proportions indicated in Fig. 2b. It is shown that the industries, including the manufacture of coke here appearing as a separate sector, are by far the largest consumers of coal.

It is interesting to note also that, from the standpoint of the central station, the industrial load is the most important to the central station for several reasons. The January 1, 1921, issue of the *Electrical World* gives an account of a comprehensive nation-wide survey of industrial loads carried by central stations, which shows that 28.4 per cent was sold to lighting customers, 57.2 per cent to power customers including electric railways, and 14.4 per cent was allowed for line and distribution losses. Later data secured but not appearing in this article show that approximately $13\frac{1}{2}$ per cent of this total load may be charged to the electric railways. This relationship is shown in Fig. 2c.

Aside from the magnitude of this industrial load furnished by the central station, it is interesting to study some typical load curves of central stations where the total load is segregated into its component parts for lighting, railways and industrial power. Figs. 3 and 5 are typical load diagrams from two central stations, located in two of our larger cities. In these curves no one type of load predominates, but the aid of the industrial load in raising the load factor is clearly apparent.

A totally different division of load is shown in Fig. 4. This was taken from a central station in a manufacturing city of moderate size, where the industrial load was almost entirely from textile mills. Here the industrial load predominates as shown by Curve A. Curve B shows power transmitted at 22,000 volts over a large area; Curve C is distributed at 2200 volts and constitutes the local lighting and small power load; and Curve D represents station service and series arcs. The maximum railway load in this case is about 500 or 600 kw. and being so small can not be shown advantageously on this diagram.

It is not practicable in the space allowed here to include load curves of many different kinds of industrial plants, but a few have been

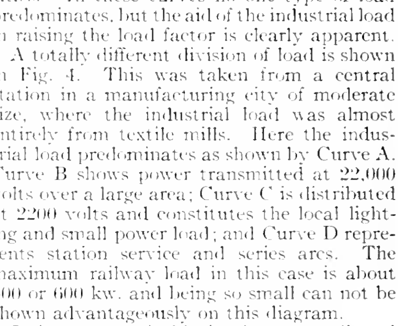


Fig. 4. Daily Load Curve in City Where Industrial Load Predominates

selected to show some of the general characteristics. (Fig. 7a to 7g.)

In considering the methods of manufacture, we know that the products of many of the industries are produced mainly by the direct application of mechanical power to

Fig. 5. Another Daily Load Curve of Central Station in Large City

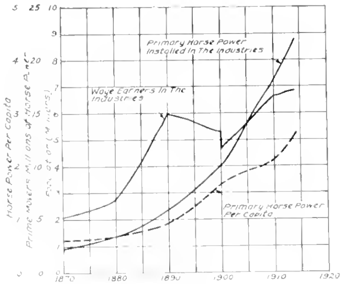


Fig. 6. Indications That the United States is Becoming an Industrial Nation (1914 Census)

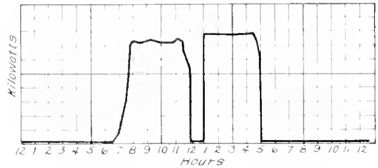


Fig. 7d. Load Curve of Shoe Factory

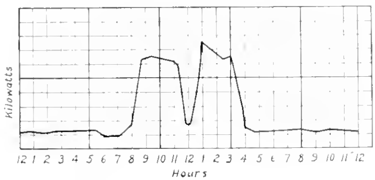


Fig. 7a. Load Curve of Shipbuilding Plant

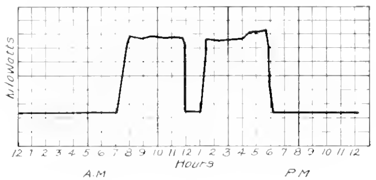


Fig. 7e. Load Curve of Brass, Bronze and Copper Products

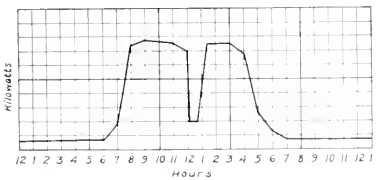


Fig. 7b. Load Curve of Marble Cutting Plant

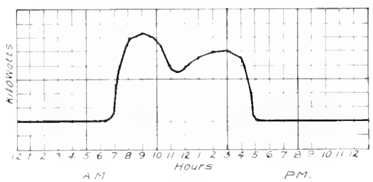


Fig. 7f. Load Curve of Packing House

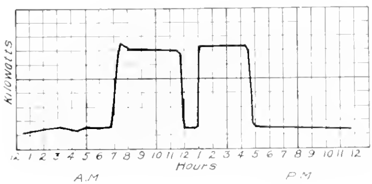


Fig. 7c. Load Curve of Textile Industry (Hosiery Plant)

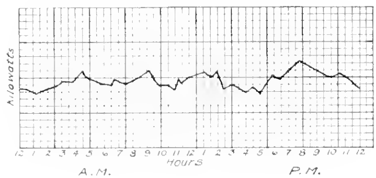


Fig. 7g. Load Curve of Cement Mill

[illegible] saws, etc. [illegible] direct application [illegible] from the raw [illegible] product. Such industries [illegible] coal at their [illegible] generate their own [illegible] the exhaust in [illegible] It is interesting to compare [illegible] amounts of coal used and [illegible] installed by some of our [illegible] industries, as shown in Fig. 8. [illegible] how the relative amounts of coal required by various industries, arranged from right to left in order of decreasing importance. Beside each dark column is a blank column representing the primary horse power installed. By primary horse power is meant the power of engines and waterwheels owned and operated by the manufacturing plants themselves plus the power purchased or rented from central stations in the form of electric current. This purchased electric power is shown by the shaded portion of each blank column. If any prime movers operated by the manufacturer generate current for their own motors, the horse power of the motors is omitted as it would mean a duplication.

The future of industries apparently will be governed by the following factors:

1. An apparently unlimited expansion of human wants.
2. An apparently unlimited increase of the number of human beings possessing these wants.
3. A constantly increasing necessity for [illegible]
4. A continuously increasing necessity for larger supply of energy.
5. The demands for constant improvement in methods.
6. A reduction in costs and an increase in the scale of living.
7. A greatly increased emphasis for the necessity of research, invention, and discovery.
8. A better and more general understanding of the fundamental principles of economics.

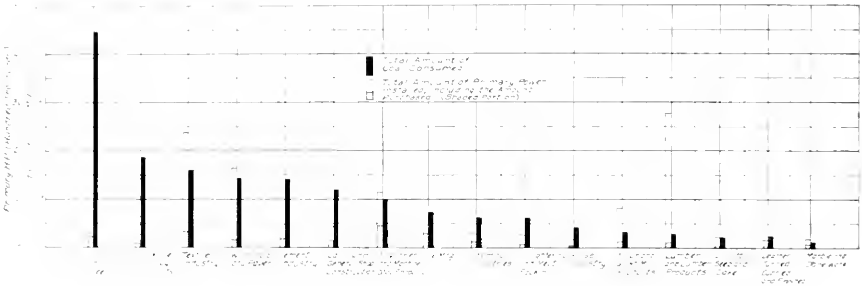


Fig. 8. Relative Amounts of Coal and Power Used by Some of the Principal Industries (1914 Census)

As our standards of living go higher our requirements multiply. To satisfy these newly found wants the industries exist and must continue to increase. While the population of this country has increased 270 per cent since 1870, the number of wage earners in the industries according to the census has increased over 700 per cent. The increase is doubtless even greater than this, because prior to 1909 the census included individuals engaged in what were known as hand, neighborhood and building trades, who are now no longer included by the census in this classification. It should also be considered that the productiveness of each industrial worker assisted by modern methods and machinery is many times greater than formerly.

During the past century the chief occupation of the people of the United States has changed from agriculture, stock raising, and lumbering to manufacturing, and the future power demands of our steadily growing manufacturing industries can hardly be estimated at this time.

The Use of Central Station Power in Mines and Steel Plants

By K. A. Pauly

Power and Mining Engineering Department, General Electric Company

K. A. Pauly

PERHAPS in no other field of application of the electric motor are the conditions more favorable for the sale of central station power than in mining. The load curve of a single mine is a combination of a very fluctuating hoist load with high peaks superimposed on a fairly uniform demand of the drill compressors, ventilating fans, pumps, etc., making the isolated plant at the mine high in first cost and expensive to operate. Fuel is expensive at metal mines and seldom if ever is condensing water available in sufficient quantities at either metal or coal mines, and it is frequently necessary to purchase drinking water to supply the boiler feed. The control of a large number of mines by a single company usually does not afford relief because the individual mines are so scattered that supplying power for all from a single station centrally located involves too great an outlay in transmission lines, because advantage cannot be taken of the load of intervening mines operated by other companies. Even where the conditions are reasonably favorable for the economic generation of power, many mine operators feel that they can realize greater returns by spending the capital required to build a generating station in other branches of their operations. On the other hand they gladly avail themselves of an opportunity to purchase power, thus reducing the first cost of electrification by the cost of the power plant.

A mine load differs from others in several essential details which must be taken into consideration by the central station engineer if he is to be successful in his efforts to serve his patrons. The failure of power, even for short periods only, may endanger the lives of hundreds of men under ground by an accumulation of explosive gases caused by shutting down the ventilating fans, and because of this danger every reasonable precaution should be taken to guard against interruptions in the service. At certain seasons of the year large volumes of water find their way into the mines and serious damage may follow interruptions in the pumping. The writer has been informed by the superintendent of one of the large anthracite mines that during the wet season the pumps will be flooded in one hour if shut down, and that it required several weeks to pump this mine dry after an accident in the boiler plant which made it necessary to shut off steam for a comparatively short time.

Feeding the mine over double lines, preferably on separate poles or by a loop circuit, minimizes the danger from interruptions due to transmission failures. Modern lightning arresters properly placed and maintained will eliminate many delays due to lightning disturbances. By generating power in two or more stations with sufficient capacity to keep the pumps and fans running, insurance will be had against serious damage to the mine from accidents in one of the plants.

From the standpoint of safety and reliability the installation as a whole may be bad in spite of any precautions which the power company may take unless care and intelligence are exercised in the purchase and installation of the equipment underground; and unless the mining company maintains a competent engineering department it will do well to engage the services of an experienced consulting engineer. Rules governing standards of practice in the installation of electrical equipment in mines are being extensively discussed and work on their preparation is now well under way, but it will be some time before they can be put into force. However, even with these at his disposal it will be to the interest of the operator to consult an experienced engineer in making his installation.

In the electrification of its mines, America lagged behind Europe largely because electric power was not available in most mining districts, and where available its use for mining operations was handicapped by such restrictions that few operators availed themselves of the opportunity to purchase it. The hoist load with its high peaks of short duration was not looked upon with favor by power companies, and this was largely responsible [illegible] made in mine electrification [illegible] where power was available.

Attempts were made at first to avoid the hoist load, leaving the hoists to be steam operated and electrifying the compressors, pumps, etc., but only a moderate degree of success was attained. The hoist load is the element of the mine load which contributes mostly to the inefficiency of the steam plant and the conversion of only the constant load to motor drive frequently meant simply the addition of the cost of electric power to the former cost of steam operation and under the most favorable conditions only a comparatively small saving in the total cost for power. It soon became apparent that if real progress was to be made the whole mine boiler plant must be eliminated.

Systems of hoist load equalization were developed to relieve the power system of the peaks due to the hoist, and these removed the objectionable characteristics of this load from the standpoint of the power company. However, the first cost of the electrical equipment was so great as to limit the electrification of hoists to the most favorable cases.

Finally the power companies, appreciating that with a large connected mining load the peaks of the individual hoists would so interweave as to give a reasonable load factor and that the mining load could not be obtained without making a more favorable proposition to the miners, changed their attitude and considered the load conditions which would obtain with a large connected load instead of dealing with each case independently of all the others. Permission was granted to use large induction hoist motors or direct-current motors with Ward-Leonard control, but without provision for equalization of the peaks where the induction motor was either inefficient or for other reasons was unsuited to the work. The success that attended their efforts is indicated by Table I which gives the power sold during the last year by some of the large companies serving mining districts.

The load factors vary from approximately 15 per cent for the single mine to approximately 70 per cent for large group of mines. One of the most important facts revealed by these figures is the extent to which electrification has taken place in coal mines, which is conclusive evidence both of the advantage of electric power over all others for mine operations and of the wisdom of purchasing power when available.

TABLE I

Power Company	Annual Power Consumption Kw-hr.	Material
1	617,600,000	Metal
2	148,500,000	Coal
3	102,000,000	Coal
4	98,853,201	Metal
5	85,000,000	Coal
6	70,000,000	Metal
7	68,000,000	Coal
8	63,515,452	Coal
9	52,000,000	Metal
10	48,948,000	Metal
11	46,031,827	Coal
12	42,803,860	Coal
13	34,000,000	Coal
14	30,355,809	Metal
15	30,000,000	Coal
16	28,636,000	Coal
17	28,000,000	Metal
18	27,642,000	Coal
19	26,302,927	Coal
20	25,000,000	Metal and Coal
21	25,000,000	?
22	23,822,595	Coal
23	22,749,050	Coal
24	14,070,500	Coal
25	13,498,394	Metal
26	10,195,425	Coal
27	7,500,000	Coal
28	7,000,000	Coal
29	7,000,000	Metal
30	4,000,000	Metal
31	3,500,000	Metal
32	3,275,000	Coal
33	3,000,000	Metal
34	1,500,000	Coal
Total ..	1,819,300,040	

Steel Plants

In steel plants the conditions are very different from those obtaining at the mines. The chemical reactions which take place in the reduction of the iron ore in the blast furnace produce immense quantities of gases which can be utilized as fuel either in internal combustion engines or by burning them under boilers. The amount and thermal value of the gas vary with the amount of coke required to reduce the ore, but under ordinary conditions a furnace yields about 150,000 cu. ft. of gas per ton of pig iron produced, the gas having a thermal value of from 90 B.t.u. to 110 B.t.u. Of the power that is thus made available, about 55 per cent is required to supply the blast for washing the gases and for the other auxiliaries at the blast furnace proper, leaving 45 per cent available for power for other purposes in the plant.

In the manufacture of metallurgical coke used in the blast furnace there is produced about 11,000 cu. ft. of gas per ton of coal fired, having a thermal value of approximately 550 B.t.u. per cu. ft. This gas may be mixed with the blast furnace gas and burned under boilers, but because of the high hydrogen content it is not well adapted for use in internal combustion engines. It is, however, an excellent fuel for reheating and open-hearth furnaces and is therefore generally used there rather than for power purposes.

Several attempts with varying degrees of success have been made to utilize the waste heat of the open-hearth furnaces, but this development has not reached extensive proportions as yet. Careful analysis of the heat balance of a modern steel works comprising blast furnaces, open hearths, by-product coke ovens and rolling mills producing blooms, billets, rails, structural shapes and plates indicates that enough energy is available as a by-product to supply all the needs of the plant, and this general conclusion seems to be borne out in practice.

Because of the theoretically high efficiency of gas engines operating on the waste gases from the blast furnace they were used in the earlier installations in this country as well as abroad, but they have taken a place second to the steam turbine because of their high first cost, their comparative unreliability, and the fact that under operating conditions their efficiency falls far below that anticipated when they were first introduced. Also, improvements in the design of steam turbines and in the method of cleaning the gas which conserves a large part of its heat as it leaves the stack make the comparison between the gas engine and the steam turbine less favorable to the former now than a few years ago. In fact, power can be produced in a modern turbine plant operating on blast furnace gas as a fuel cheaper than it can be produced in a gas engine plant, all factors being considered.

Where the conditions are so favorable for local generation of power as they are in the large steel plants it is not to be expected that there will be a very large market for central station power, but there are many small plants which do not operate blast furnaces or coke ovens from which to draw by-product fuel which can to advantage and do purchase power from public utilities serving their territories. Because in the early steel mill installations power was developed at 25 cycles there appears to be considerable unjustifiable prejudice in favor of this frequency on the part of many steel mill electrical engineers. It is true that the large low-speed direct-connected motors are cheaper when designed for 25 cycles than for 60 cycles, and most of the early installations included motors of this class; but the factor most responsible for 25 cycles in steel plants is probably the gas engine with which it was extremely difficult to obtain satisfactory operation at higher frequencies.

This subject has been quite extensively discussed recently and the following is quoted from a contribution by the writer to the discussion of a paper on this subject presented at a recent meeting of the Association of Iron and Steel Electrical Engineers:

"From the standpoint of production, both as to quantity and quality, steel can be successfully produced by either 25-cycle or 60-cycle power, and the question as to which frequency should be used in the electrification of any plant is one which must be answered by the executives of the interested company, acting under the advice of their respective engineers, since the vital factors affecting the choice are of such a nature that their importance cannot be properly appraised from without. A determining factor in the case of one plant may be worthy of only minor consideration in another, although this may not be at all apparent without knowledge of facts possessed only by the executives of the steel company.

"There are, however, certain rather clearly defined advantages which apparatus designed to operate at one of these frequencies possesses over that for the other, and a very brief review of these may be of assistance in a preliminary study, although final conclusions should be based on a careful analysis of the exact conditions obtaining in each case.

"Generating and transforming equipment, including motor-generators and synchronous converters, for supplying power for the direct-current auxiliaries are less expensive per kilowatt or kilovolt-ampere on 60 cycles. For general purpose alternating-current motors, 60 cycles makes possible a greater number of speeds within a given range, although no serious inconvenience has resulted from the limited number of speeds available where 25 cycles have been adopted. Sixty-cycle general purpose motors are also slightly cheaper, but the sum total cost of these units is only a small item in the total cost of the electrical equipment in a normal steel plant. In fact, except for the main roll motors, 60-cycle equipment seems to have the advantage in the first cost.

"Whether constant speed main roll motors are cheaper for 60 cycles or 25 cycles depends upon their capacities and speeds. For large direct-connected motors, 60-cycle equipments [illegible] than the corresponding [illegible] and their power-factor [illegible] which increases the [illegible] load, and of generating and [illegible] equipment if power is generated [illegible] true that the power-factor [illegible] 60-cycle motors can [illegible] that with 25-cycle units by [illegible] synchronous condensers, but [illegible] are placed near the motors the [illegible] transforming and transmitting equipment between the generating station and the motors will not be affected by their [illegible]. Due allowance for this and for the cost of the synchronous condensers, wherever located, must be made in the cost of the 60-cycle installation.

"The substitution of high-speed 60-cycle motors geared to the mills will lower their costs, including the gears, slightly below those for the 25-cycle direct-connected units, but the operating handicap of the gears must not be lost sight of. The smaller moderate speed main roll motors are, in general, slightly lower in cost for 60 cycles.

"Adjustable speed alternating-current main roll motors may be made for either frequency, and in general are affected by speed and frequency similarly to the constant speed units.

"We have analyzed the conditions obtaining in several large steel plants, from which the following conclusions are deduced, which conclusions, I believe, will apply in general to large and moderately large plants.

"If power is generated locally and the large main roll motors are direct-connected the capital cost of the 60-cycle installation will be 10 per cent to 15 per cent greater than that for the 25-cycle installation and if power is purchased this difference may be doubled although, of course, the cost of generating equipment will be saved. The efficiency, which I have purposely refrained from discussing in detail because of its dependence upon so many factors, such as power-factor, gearing, etc., will be practically the same for both frequencies for the plant as a whole.

"Based upon the facts as revealed by our detailed study of the plants referred to, I feel justified in making the following general recommendations

"Where power can be purchased at an attractive rate and there are no reasons, apart from the question of frequency, for not purchasing it, power should be purchased and the equipment designed, of course, for the frequency of the power supplied, which will [illegible] almost universally 60 cycles whether or not it is intended at a later date to generate power locally.

"If power is to be generated locally, the overall first cost of the electrical equipment will be less for 25 cycles, but the decision to adopt this frequency should not be made until due consideration has been given to the advantage of tying-in with the public utility supplying the district.

"Two vital factors upon which the decision to purchase or generate power must be based are: First, the importance of making the plant self-contained; and second, the return which may be realized on the money required to build the local generating plant if utilized for development along other lines. Obviously the weight of these factors must be determined by the plant executives as previously suggested. If blast furnace gas or by-product fuels from any other source are available, conservation demands their utilization, which can, in general, best be accomplished through the generation of electric power locally.

"In this discussion I have assumed that the choice of frequency is not hampered by an existing development. Obviously the inertia of a partial electrification along one line may be such as to make it necessary to proceed along this line, although a different course could advantageously be pursued, if not hampered by an existing installation."

TABLE II

Power Company	Annual Power Consumption Kw-hr.
1	135,000,000
2	92,000,000
3	78,403,000
4	70,000,000
5	49,386,000
6	48,000,000
7	40,697,000
8	35,705,000
9	33,000,000
10	28,598,196
11	28,000,000
12	21,027,000
13	11,800,000
14	10,434,000
15	9,856,600
16	9,782,500
17	8,581,813
18	2,540,000
Total	712,832,109

While a steel mill load is made up largely of a combination of high peak loads these peaks recur at short intervals and are of very short duration, the daily load-factor being not very different from that of the ordinary industrial plant. The extent to which electric power is supplied by public utilities to steel plants is indicated by Table II which gives the approximate power sold annually by some of our large central stations for operating steel plants. The load-factors for these installations range from 26 to 72 per cent. As a matter of fact over half of the plants in this list have a load-factor of 40 per cent or better. It is interesting to note that of the companies listed only one supplies 25-cycle power.

Steel Mill Power-factor and the Central Station

By A. K. Bushman and A. L. Lemon

Power and Mining Engineering Department, General Electric Company

A. K. Bushman

THE characteristics of equipment in steel mills are such that the induction motor is almost universally used with the exception of certain auxiliaries. All induction motors draw their excitation from the line in the form of lagging current. Since a large low-speed motor requires more excitation than one of higher speed, the full-load power-factor of the low-speed machine is lower. The approximate relation between the number of poles and power-factor of a 1000-h.p., 2200-volt, 3-phase, 60-cycle, 40-deg. motor is shown graphically in Fig. 1.

The principal divisions of a steel mill load are:

(1) Large induction motors for main roll drive.

(2) Motor-generators or synchronous converters for supplying direct current.

(3) Auxiliary alternating-current motors (synchronous or induction).

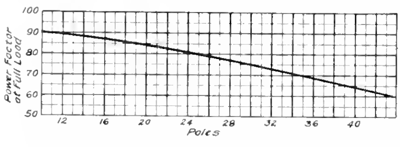
(4) Alternating-current lighting.

(5) Electric furnaces.

Analyzing these with regard to power-factor: Synchronous converters usually operate at unity power-factor. Motor-generators are usually of the synchronous type if larger than 100 kw. and are rated at 85 per cent or lower leading power-factor and are thus able to supply sufficient leading wattless kilovolt-amperes to correct for a considerable amount of the lagging wattless kilovolt-amperes required by the induction motors. A large number of auxiliaries such as pumps, air compressors, etc., are synchronous-motor driven at unity dower-factor. Alternating-current lighting and electric furnaces operate at practically unity power-factor. Thus, power-factor correction need be considered only in connection with the induction motors, both main roll and auxiliary.

A. T. Lemon

In any steel mill the main roll motors are comparatively few in number but, owing to their size, form a large part of the total load. Due to the nature of the work many main rolls run at low speed and therefore require either a low-speed motor or the use of gears. If the power supply is 60 cycles, the use of direct-connected low-speed motors means very low power-factor, as will be seen by reference to Fig. 1 which shows that the full-load power-factor of motors of similar design is a function of the number of poles and not of the actual speed of the motor in r.p.m. Some of these motors require as much as 30 per cent of their full-load current for magnetization, and on account of the intermittent character of the load on some types of mills and since the magnetizing current is practically constant for all loads, the average power-factor is considerably lower than that for full load.



ig. 1. Approximate Relation Between Full Load Power-factor and the Number of Poles of a 1000-h.p., 40-deg., 2200-volt, 3-phase, 60-cycle Induction Motor

[illegible] formers, and lines upon [illegible] induction motor must carry [illegible] magnetizing current [illegible] must be larger than would [illegible] power-factor were [illegible] the advantage of both

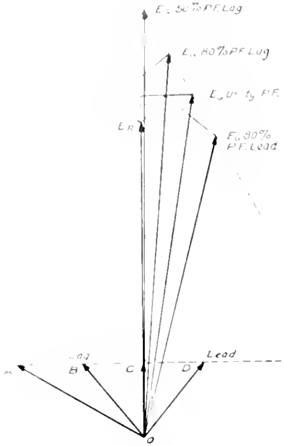


Fig. 2. Influence of the Power-factor of the Load on the Voltage Drop in a Transmission Line

the central station and the steel mill to keep the power-factor high. The central station is benefited because its generating capacity is kept at a minimum for a given connected load.

coal fired is almost negligible. To the customer, low power-factor means increased investment in transformers, transmission copper, and devices, as well as low and fluctuating voltage for line drop is very sensitive to power-factor as will be shown.

The resistance drop is in phase with the line current and hence always has a component opposing the generated voltage. The inductive drop lags 90 deg. behind the line current and so for low lagging power-factor loads has a large component opposing the generated electromotive force. As the power-factor increases this component decreases to zero and finally at some value of leading power-factor, depending on the constants of the line, becomes additive and the receiver voltage is greater than that generated.

This is clearly shown in Fig. 2 which also shows how the generator voltage will have to vary with varying power-factor in order to maintain constant receiver voltage. In the diagram the vector OE_R represents the receiver voltage, which is kept constant. The kilowatt input to the load is also kept constant, the vectors OA, OB, OC, and OD representing the line current at 50 per cent lagging power-factor, 80 per cent lagging power-factor, unity power-factor, and 80 per cent leading power-factor respectively, the power component being OC in each case. Adding (geometrically) to OE_R the resistance line drops parallel and proportional to the load currents, and to the end of these the inductive drops at right angles and proportional to the load currents, we have the generated voltages required to maintain constant voltage on the load at varying power-factor.

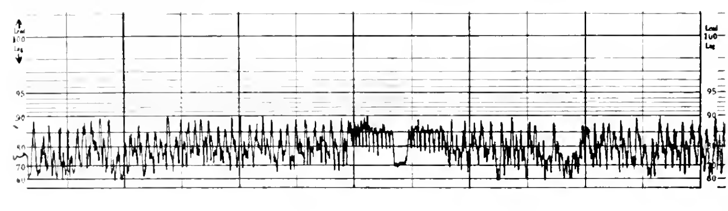


Fig. 3. Typical Power-factor Chart for One Department of a Large Steel Mill

It costs practically as much to generate and sell 1000 kv-a. at 70 per cent power-factor as 1000 kw. at unity, since the same investment in equipment and the same overhead charges apply in either case and the difference in the

Low voltage is very objectionable in a steel mill as the major part of the load is on induction motors and with this type of machine the horse-power output with constant-current input varies approximately inversely as the square of the impressed voltage. Also, if the lighting circuits are alternating-current, low voltage means greatly decreased brilliancy and fluctuating voltage causes flickering of the lights.

It is possible to supply the wattless current from an outside source without increasing the size of the generators, transformers, or transmission lines, and thus maintain a higher voltage at the end of the line and at the same time release part of the capacity of the generating and transmission system for use elsewhere. The most commonly used power-factor corrective apparatus is the synchronous motor or synchronous condenser, as it is called when used for power-factor correction only. A synchronous motor can be made to supply all of the magnetizing current required and the generators will then operate at unity power-factor. Under these conditions the maximum power can be delivered with minimum expenditure for generators and transmission equipment. On a system with very low power-factor, the saving in line material alone will sometimes pay for the machinery installed for improving the power-factor and a material saving in operating expense is realized thereafter.

Some mills not only correct poor power factor but also maintain constant receiver voltage by installing a condenser whose excitation is controlled by a voltage regulator which causes the condenser to supply leading current when the voltage tends to fall below normal, the amount of leading current decreasing when the load drops and the voltage tends to rise above normal. These condenser installations can be made entirely automatic, the starting and stopping being governed by load or voltage conditions or by a time clock, and only an occasional inspection by an attendant is necessary.

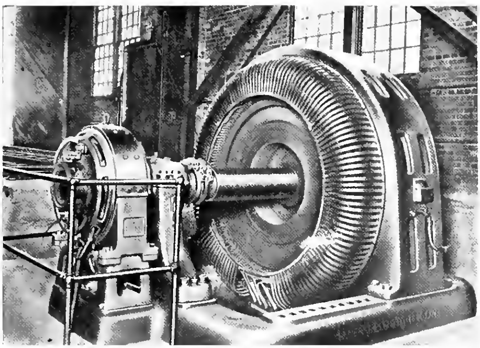


Fig. 5. 5000-kv-a., 600-r.p.m., 2300-volt Synchronous Condenser with Direct-connected Exciter, Trumbull Steel Co., Warren, Ohio

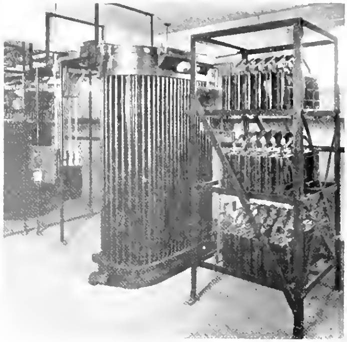


Fig. 4. 180-kv-a., 3-phase, 60-cycle, 6600-volt Static Condenser Equipment, Public Lighting Dept., Detroit, Mich.

In a large steel mill there are a number of auxiliaries that can be driven by synchronous motors and the steel mill engineer should be urged to use this type of motor wherever possible. If designed for 70 per cent power-factor they can be used for power-factor correction, supplying 70 per cent of their kilovolt-ampere rating for this purpose and 70 per cent for driving a mechanical load. The total capital invested in machinery with this arrangement is less than where two separate machines are used totaling the same kilovolt-amperes, that is, using one machine for supplying the necessary magnetizing current and another for driving the mechanical load.

In recent years the variety of products required from a steel mill has created a demand for mills capable of quick adjustment and therefore driven by adjustable-speed motors. Motors with multi-polar connections are inherently lower power-factor machines than single-speed motors and, in addition to giving only two or three speeds with no intermediate adjustment, are rather expensive, so their use has been rather limited.

[illegible] ...ble-speed and high [illegible] has been very satis[illegible] ...able-range modified S[illegible] ...peed control of induc[illegible] re...aining all the advan[illegible] ...nduction-motor drive. T[illegible] ...ill operate over a wide ra[illegible] and below synchronous speed at [illegible] friction to full load at a power-factor [illegible] poorer than 95 per cent lagging at [illegible] speed setting, including synchronism. The use of this popular system of drive eliminates the wattless kilovolt-amperes impressed on the line by large induction motors, and unless there are other motors on the line drawing wattless current the purchase of power-factor corrective apparatus is not necessary.

As has been mentioned, the use of high-speed instead of low-speed motors will improve the power-factor but until recent years this was not satisfactory for main roll drive on account of the difficulty of building large gears that would stand up under the service required of them. Improvements in manufacturing methods and in the design of the gears themselves have made them thoroughly reliable, and there is an increasing tendency on the part of the steel mills to use them in connection with high-speed motors to obtain a smaller investment in installed apparatus in some instances and a much better power-factor.

In isolated steel mills where only a small amount of corrective apparatus is required, the static condenser satisfactorily meets the conditions. In small sizes this piece of apparatus has several advantages over a synchronous condenser. It has a lower initial cost, operates with lower losses, and therefore at a lower temperature rise; it has no rotating parts, therefore, no lubrication costs, no bearing wear; and its operation is noiseless. It is easier to put on and take off the line as this is accomplished simply by closing or opening an oil circuit breaker. However, its corrective capacity is fixed and leading only, and is not adjustable for either leading or lagging current as is possible with a synchronous condenser. It also takes more floor space per kilovolt-ampere and in large sizes costs more per kilovolt-ampere.

The matter of charging for power on a sliding scale basis, that is, on a power-factor instead of a kilowatt basis, while not new had not been given close attention until emergencies arose making it necessary to investigate the possibility of taking on additional customers or of relieving the generating station of its load. With the increasing tendency to enforce the power-factor clause in contracts, the steel mill engineer is facing the problem of buying power-factor corrective apparatus or paying more for the power he uses. It may happen that the central station is bound by contract to supply power at a certain rate on a kilowatt basis regardless of the power-factor, in which case the benefit to the steel mill from installing synchronous condensers, thus securing better voltage regulation, may not warrant the expense. Under conditions such as these, if the central station is running somewhere near its rated kilovolt-ampere capacity and has an opportunity to take on additional customers, it must either install more generators or synchronous condensers to relieve the generators of the wattless load. The purchase of additional generators, turbines, etc., may not be advisable at the time but the extra income from the new load will represent a fair return on the smaller capital required for the purchase of synchronous condensers. These could be installed in the station but the logical place for them would be in the steel mills drawing the largest wattless load as the transmission system would then also be relieved.

Since the benefits derived from power-factor correction are shared by the central station and the steel mill it is to the interest of both to study the problems of their particular systems and with the aid of the electrical manufacturer endeavor to eliminate the waste caused by low power-factor. Marked results due to correction of power-factor have already been accomplished and the future will undoubtedly show continued improvement keeping pace with the constant progress toward increased efficiency.

Load Conditions in Steel Mills

By J. D. Wright and L. C. Mosley
Power and Mining Engineering Department, General Electric Company

J. D. Wright

A CURVE-DRAWING wattmeter record of the total power delivered to a steel mill shows a load curve which is a combination of individual power demands varying from the more or less constant loads of motors driving multi-stand mills and constant running auxiliaries to the intermittent and rapidly applied loads of motors driving single-stand mills and fast reversing auxiliaries. It is the purpose of this paper to describe load conditions in steel mills as illustrated by typical individual rolling mill motor load cycles and to show their effect on the total load curve.

REVERSING BLOOMING MILLS

The motor driving a reversing blooming mill is undoubtedly subjected to the most violent load fluctuations encountered in any rolling mill drive. If it were necessary to supply power for this motor direct from the power house it would be a very undesirable load However, operating conditions require the use of a direct-current motor, and the Illgner system of control is therefore used. Power for the reversing mill motor is obtained from a flywheel motor-generator consisting of one or more generators, a flywheel and a slip-ring type induction motor. The induction motor is usually wound for 2200 or 6600 volts, and takes its power direct from the incoming power lines.

The secondary control equipment for the induction motor consists of a liquid slip regulator. This slip regulator is provided with a torque motor, the windings of which are connected to the secondaries of series transformers located in the line leading to the primary circuit of the induction motor.

L. C. Mosley

The torque of the motor will vary with the line current and if when the load comes on the current tends to exceed a certain predetermined value the torque of the motor will overcome the weight of the moving parts of the slip regulator, thereby introducing resistance into the rotor circuit of the induction motor driving the flywheel set, causing the latter to slow down and thus allowing the flywheel to give up its energy. During the period of light loads, when the current tends to fall below the predetermined value, the weight of the moving parts of the slip regulator overcomes the torque of the motor and the resistance will be automatically cut out and the flywheel accelerated. It is therefore evident that the slip regulator is effective in limiting the input from the line to a predetermined maximum and prevents the rapidly fluctuating loads on the main reversing motor from reaching the incoming power lines.

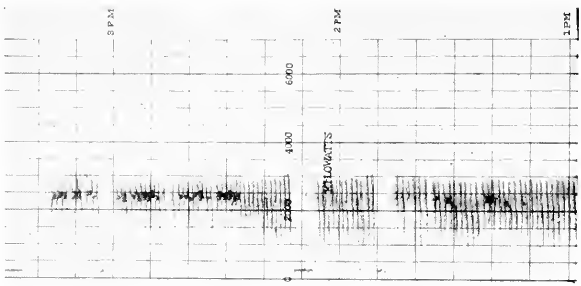


Fig. 1. Load Curve for Reversing Blooming Mill

Fig. 2 shows a typical calculated load curve for a reversing blooming mill motor. It will be seen that the momentary peak loads are as high as 13,000 h.p., but the use of the flywheel

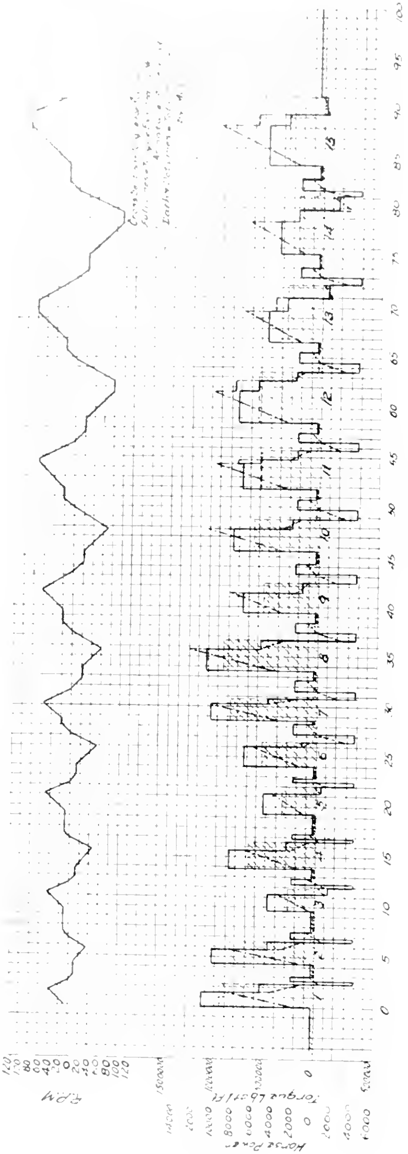


Fig. 2. Duty Cycle for Reversing Blooming Mill Motor

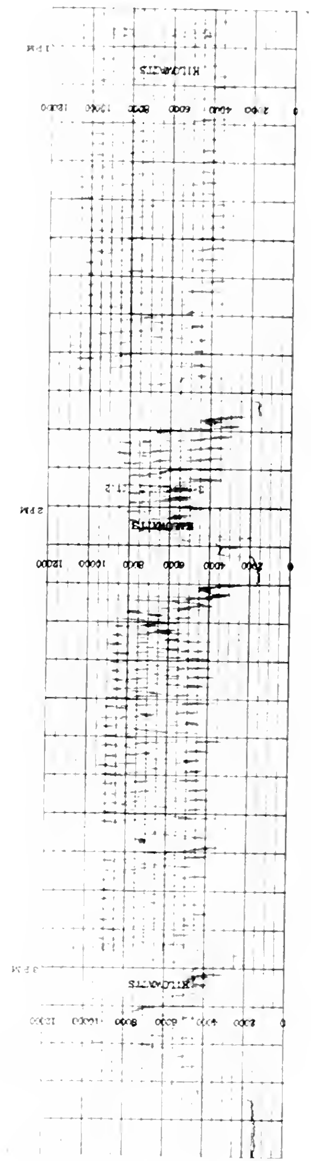


Fig. 3. Station Load Curve Showing Combination of Blooming Continuous Mills and Auxiliary Motor Loads

motor-generator with slip regulator control limits the input from the power system to a maximum of approximately 3000 kw., as shown in Fig. 1. A reversing blooming mill therefore does not impose a difficult or undesirable load on a power station. With conditions as shown by the curve in Fig. 2, the power consumed from 1 p.m. to 2 p.m. was 2200 kw-hrs., so that the ratio of average to peak load for the hour is $\frac{2200}{3000} = 73.5$ per cent. During this period the mill was idle for about five minutes. From 2 p.m. to 3 p.m. the power consumed was 2000 kw-hrs., with the mill idle approximately 10 minutes. The paper speed of this curve-drawing wattmeter was three inches per hour. A much higher paper speed, say three inches per minute, would show that due to the action of the flywheel, the load on the induction motor came on and went off gradually and not suddenly as on the direct-current reversing mill motor to which the flywheel set furnished power.

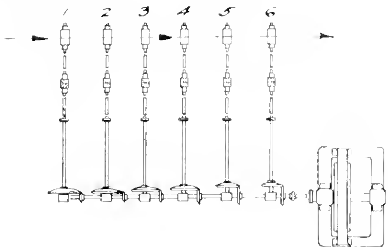


Fig. 4. Layout of Six-stand Continuous Mill

CONTINUOUS SHEET BAR AND BILLET MILLS

Load conditions on motors applied to continuous mills of this type are probably as easy as will be found in any main roll drive. A typical mill layout is shown in Fig. 4. The stands, which may vary in number from four to ten, six being quite common, are spaced with only a few feet between centers. Such a mill receives its steel direct from the blooming mill in the form of a bloom having a section of approximately 12 sq. in. and a length, for an average size ingot, of approximately 50 ft.

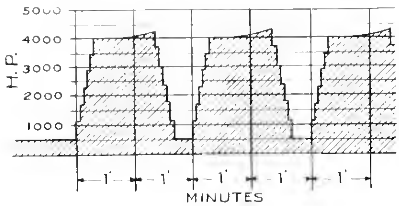


Fig. 5. Load Cycle for Six-stand Continuous Mill

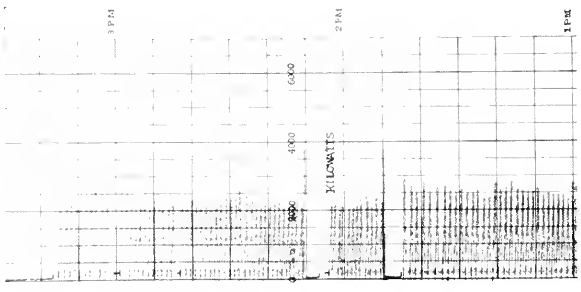


Fig. 6. Load Curve of Four-stand Continuous Mill

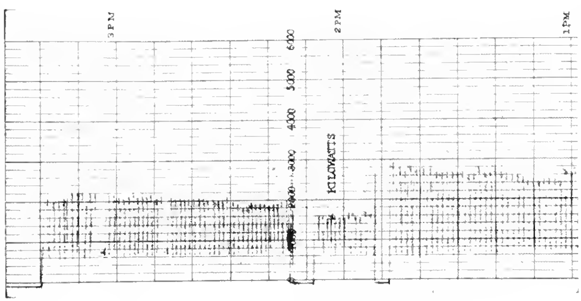
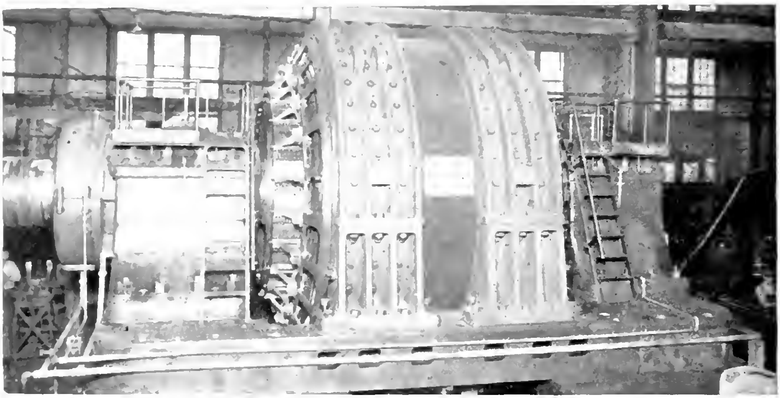


Fig. 7. Load Curve of Six-stand Continuous Mill

The [illegible] Fig. 1 [illegible] these load curves [illegible] the curve-drawing wattmeter is three inches per hour, which is of course too [illegible] to show the building up of the load as the [illegible] enter each successive stand. In Fig. 6 the power consumed from 1 p.m. to 2 p.m. was 800 kw-hrs., and from 2 p.m. to 3 p.m. 700 kw-hrs. In Fig. 7 the power consumed from 1 p.m. to 2 p.m. was 2400 kw-hrs., and from 2 p.m. to 3 p.m. 1700 kw-hrs. It will be seen from these curves that the duration of the maximum load is much greater on the six-stand mill, Fig. 7, than on the four-stand mill, Fig. 6. Such or similar arrangements of blooming, billet and sheet bar mills are quite common, and the total load curve showing a combination of these three individual mill loads, together with the load caused by the auxiliaries in these mills, will be of interest. Such a curve covering the same period of time as in Figs. 1, 6 and 7, is shown in Fig. 3. The paper speed of this curve-drawing wattmeter showing the total load is six inches per hour. The auxiliary load consisting of pumps, air compressors, motor-generators etc., remains practically constant at approximately 1500 kw. The total power consumption from 1 p.m. to 2 p.m. was 7300 kw-hrs., from 2 to 3 p.m. 6000 kw-hrs. The maximum peak during this period was 11,000 kw.



The motor illustrated was recently completed by the General Electric Company for the Tata Iron and Steel Company, India. It is a double unit machine, rated 7000 h.p. A.I.E.E. rating, with a speed range of 120-0-120 r.p.m. Speeds from 0 to 55 r.p.m. are secured by means of generator field control, and from 55 to 120 r.p.m. by motor field control. Power is supplied by a flywheel motor generator consisting of a 5000-h.p., 375-r.p.m. induction motor and three 2700-kw. generators. The flywheel weighs approximately 50 tons. The armature of the motor weighs 132 tons. The ventilation equipment for this motor and others installed in the same room will be described in an article in our July issue

Generator Requirements for Crane Motors

By H. H. Vernon
Power and Mining Engineering Department, General Electric Company

H. H. Vernon

POWER for electrically operated cranes is either supplied by a central station through substations or by an isolated plant, and the kilowatt capacity of the substation or of the generator may depend on the current peaks drawn by the motors as in the case of one crane, or by the constant power demand as in the case of a number of busy cranes.

Direct Current

For one crane that is used only occasionally the continuous rating of the generator does not enter, but the generator must be large enough to stand a load equivalent to 150 per cent of the input to the hoist motor when hoisting full load.

Close regulation of a direct-current generator supplying power to crane motors is not very essential because the torque of a series-wound motor is not affected by a reasonable drop in the generator voltage.

A busy crane requires a generator that will have good regulation when delivering power equivalent to the input corresponding to 100 per cent output of the hoist motor plus 150 per cent output of the bridge motor. In other words, for a generator that will stand not more than 150 per cent overload momentarily, the continuous rating should be at least 83 per cent of the combined kilowatt input corresponding to the ratings of the hoist and bridge motors.

A generator that is used for two busy cranes with duplicate electrical equipment should stand peaks equivalent to the sum of the ratings of the hoist motor plus three times the rating of the bridge motor on one crane.

If the power is supplied by a central station or a large generator that furnishes power to motors other than the crane motors, the equivalent continuous capacity for one light-duty crane amounts to about 8 per cent of the 30-minute rating of the hoist motor.

For a busy crane that works fully up to its capacity and has enclosed direct-current motors, the equivalent continuous kilowatt load amounts to about 30 per cent of the input corresponding to the sum of the 30-minute ratings of the hoist and bridge motors. This is due to the fact that the continuous output of an enclosed direct-current crane motor, as shown by many tests, averages about 30 per cent of its 30-minute rating.

The power required for two cranes that are worked up to full capacity and have duplicate electrical equipment would be for enclosed motors about 30 per cent of the input corresponding to the sum of the 30-minute ratings of the hoist motor on one crane plus the bridge motors on both cranes.

An industrial plant with a large number of overhead travelling cranes that are in use continuously and are equipped with direct-current motors requires an average number of kilowatts equivalent to 12 or 15 per cent of the input corresponding to the 30-minute ratings of all of the hoist and bridge motors.

Alternating Current

Alternating-current crane motors must have not less than rated voltage impressed at the motor terminals because the torque of an induction motor varies as the square of the impressed voltage, therefore the generator must be large enough to have good regulation.

The remarks in regard to peak requirements for direct-current generators apply as well to alternating-current generators, but the heating requirements are different because the average continuous rating of an open-type alternating-current crane motor is about 80 per cent of the 30-minute rating.

A crane with open-type alternating-current motors doing the same work as a crane with enclosed direct-current motors requires about 30 per cent of the kilowatt input corresponding to the sum of the 30-minute ratings of the hoist and bridge motors. Two of these alternating-current cranes furnished with duplicate electrical equipment and doing the same work as two cranes with enclosed direct-current motors would require about 30 per cent of the input corresponding to the sum of the 30-minute ratings of the hoist motor on one crane plus the bridge motors of both cranes.

If these alternating-current cranes are operated up to their capacity, the 30 per cent value should be raised to 70 per cent.

The power required for heavy duty cranes equipped with open-type motors is dealt with elsewhere in this issue in an article entitled "Substation Capacity for Heavy Duty Material Handling Cranes."

Substation Capacity for Heavy Duty Material Handling Cranes

By W. C. Raube
Engineering Department, General Electric Company

W. C. Raube

For certain heavy duty cranes, such as are used for handling coal and ore on docks, it frequently is necessary to design a substation which is used only for supplying power to the cranes. The peculiar intermittent motions on the cranes cause this to be a rather complicated task in which the element of chance enters to a great extent. The following method of solving this problem has been worked out in a mathematical way, making use of one assumption as to the chance involved.

The first step in solving a problem is to determine the duty cycle of power input to any one crane. Such a duty cycle can be easily supplied by the manufacturer of a crane, because its operation is very well understood. Fig. 1 shows a duty cycle for a crane of this kind plotted with time as abscissae and kilowatt input as ordinates. The duty cycle is repeated once every 48 seconds. Actually power is drawn from the line for 30 seconds out of the 48 seconds. The duty cycle represents the combined input to the hoist motor and some traversing motors. The root-mean-square value of input is 221.5 kw. The arithmetic average value of input is 141 kw.

In studying this problem, it is readily apparent that if only one crane is being supplied with power the substation should have heating capacity of 221 kw. continuously, but if two such cranes are to be supplied, the next question to solve is the substation capacity for supplying both cranes. Fig. 2 shows the power input to two cranes when all operations of the two cranes are performed simultaneously. The root-mean-square value of kilowatts for this combination is 443, or just twice the value of one crane shown in Fig. 1. It is quite possible, however, that one crane would be doing the hardest part of its work while the other crane is at rest. Such a condition is shown in Fig. 3 which represents the input to two cranes when one crane is consuming power and the other crane is consuming no power, and the duty cycles of the individual cranes are superimposed on each other so as to cause the least possible heat at the substation. The root-mean-square value of the kilowatt input is 322 as against 443 in Fig. 2. This is a difference of 37½ per cent, which is too large to be overlooked. It is not probable that two cranes would operate always as shown in Fig. 2, nor always as shown in Fig. 3. For the purpose of this calculation an assumption was made that the two cranes would start off as shown in Fig. 2, and that one crane would gradually drop behind the other two seconds on every cycle. Input curves were plotted for 24 such conditions and the root-mean-square of the whole series of curves plus the input of one duty cycle shown in Fig. 1 was taken. The extra duty cycle in Fig. 1 was thrown in to make up for the fact that during 24 combination duty cycles one crane made 24 trips, and the other crane made 23. The root-mean-square value thus obtained was 372 kw. Fig. 4 shows the particular one of this series of combination duty cycles whose root-mean-square is 372 kw.

This value of 372 kw. is practically midway between the root-mean-square of Fig. 3 and the root-mean-square of Fig. 2. It is also interesting to note that it is practically equal to the sum of the root-mean-square of Fig. 1, plus its arithmetic average value.

Power Input to Three Cranes

It is, of course, evident that when there are three cranes on the dock, they will have a greater diversity factor than will two cranes, and in order to arrive at some value for this condition Fig. 4 was taken as being the typical input curve for two of the cranes. The third crane, whose duty cycle is as shown in Fig. 1, was superimposed on Fig. 4 in 24 different combinations, dropping back two seconds each time and then one curve, Fig. 1, was added in. The root-mean-square average for the whole combination was found to be 488 kw. It is interesting to note that when the input of the three cranes was joined together

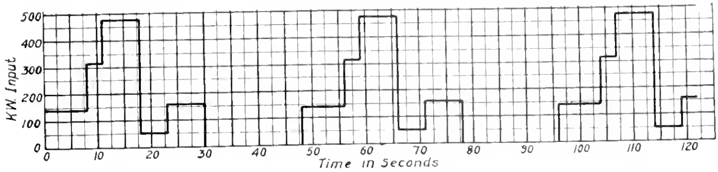


Fig. 1. Duty Cycle of Material Handling Crane. Root-mean-square equals 221½ kw.

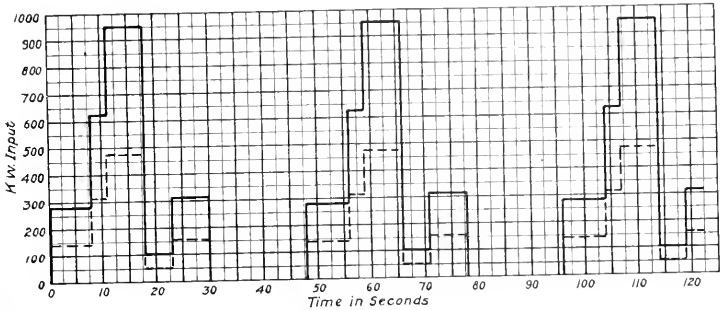


Fig. 2. Duty Cycle of Two Cranes Operating in Unison. Dotted line indicates duty cycle of single crane. Root-mean-square equals 443 kw.

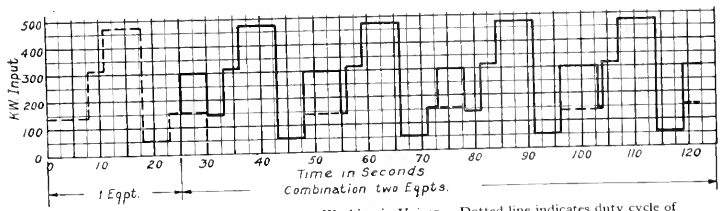


Fig. 3. Duty Cycle of Two Cranes Not Working in Unison. Dotted line indicates duty cycle of single crane. Root-mean-square equals 322 kw.

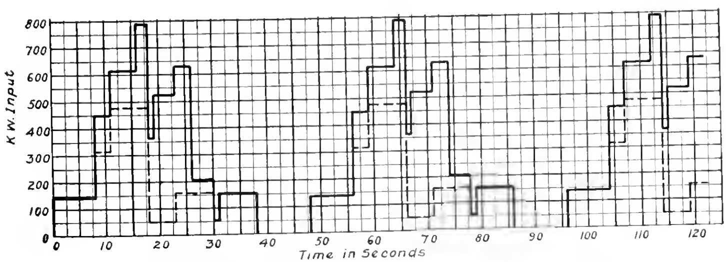


Fig. 4. An Average Duty Cycle Curve of Two Cranes Not Working in Unison. Dotted line indicates duty cycle of single crane. Root-mean-square equals 372 kw.

in the most advantageous manner, the root-mean-square was 372, whereas if the three were added together in the most disadvantageous manner the root-mean-square was 600. It is also interesting to note that 488, which is the root-mean-square input for three cranes, is practically equal to the root-mean-square of Fig. 1 plus two times its arithmetic average value.

Conclusions

It seems fair to conclude that if the cranes are going to run in all kinds of relations to each other and are going to be allowed to assume various relations according to chance, the following empirical rules would be of use in estimating the proper substation capacity:

1. For two cranes, use the root-mean-square value of input to one crane plus the arithmetic average value of input to one crane.
2. For three cranes, use the root-mean-square value of input to one crane plus twice the average value of input to one crane.

It is also, of course, necessary to supply apparatus which will stand a large number of repeated operations where all of the cranes are consuming power in the worst possible combination—that is, all three cranes drawing their maximum peak simultaneously.

Automatic Substations for Mining and Industrial Power Loads

By M. A. Whiting and C. E. H. von Sothen
Power and Mining Engineering Department, General Electric Company

M. A. Whiting

During the past year the managements of many mining and industrial enterprises have shown considerable interest in the possibilities offered by automatic operation of motor-generator and synchronous converter substations. This interest has been inspired in part by the success of the automatic substation in the railway field and in part doubtless by the extensive and rapidly growing applications of automatic motor control. An added stimulus has been, of course, the rise in wages together with the difficulty in many cases of obtaining competent operators as needed. In some quarters, however, the adaptability of automatic substations to mining or industrial service has been unduly disparaged because of too narrow a conception of the nature of an automatic substation.

Automatic Substation Defined

An automatic substation is one which, at the indication of a master circuit, goes into operation by an automatic sequence, which thereupon maintains by automatic means the required character of service; which shuts down and clears itself automatically at the opposite indication of the master circuit, and which protects itself while starting, running and shutting down.

C. E. H. von Sothen

To correct a somewhat prevalent impression, it must be emphasized that a substation may be "automatic" regardless of whether it starts only on low direct-current line voltage and shuts itself down on prolonged lack of load demand, or whether the substation runs continuously over considerable periods and is caused to start and stop by a master switch, time switch, etc., or directly by the switching operations supplying the alternating-current service.

Economic Considerations

In order to make the most advantageous application of an automatic substation, or of any comparatively elaborate type of electrical equipment, it is necessary to consider the economic relation between the electrical costs and total costs, and it is equally important to consider the functional relation of the electrical operation to the total operation of the enterprise served.

The chief business of a central station is, of course, the production and delivery of electrical energy, and the cost of producing this energy is of prime importance. The major part of the technical and executive ability of a central station organization is, therefore, engaged primarily in improving the economy of generating, converting and distributing the electrical energy. In an electric railway the power bill is a formidable part of the total operating costs. Here also, considerable technical skill may be profitably expended in reducing the power bills, and comparatively elaborate means may justifiably be adopted for this purpose.

In mining and most industries, however, the conditions are quite different. In most cases the cost of electrical energy is a small fraction of the total mining or manufacturing cost. For example: In bituminous coal fields a typical energy consumption is about 3 kw-hr. per ton of coal mined, so that the cost of electrical energy is not more than 1 to 2 per cent of the value of the coal loaded for shipment. In steel plants the ratio will vary considerably but (excepting electric furnace processes) is nearly always within 4 per cent of the value of the steel produced and in many instances within 2½ per cent. In a certain large automobile plant the cost of electrical energy per car produced is about ½ of 1 per cent of the retail price of the car.

Because the profits in an industrial or mining property must come from the sale of the commodity produced, most of the technical and executive talent of the organization is engaged primarily in lowering production costs and increasing the output. While there is room for substantial improvement in the principal elements affecting mining or manufacturing costs and plant output, the management can ill afford to devote much special attention to the possibilities of 5 or 10 per cent reduction in energy cost if the entire energy cost is less than 5 per cent of the total cost of production.

Good electrical operation in industry, however, is of vastly greater importance than is indicated by the percentage cost of energy, or even by the percentage cost of maintaining the entire electrical department, since efficiency and continuity of most mining and manufacturing operations are almost completely dependent on adequate electric service. A general interruption of electric service to a mine or industrial plant causes a loss of production which lasts not only during the interruption, but in many cases after the restoration of service while the various interrelated operations are being resumed. Spoilage of material in process of manufacture or damage to appliances may be serious additional elements of loss.

It follows, therefore, that reliability of electrical service is of prime importance, but that in many classes of industry small differences of energy consumption are negligible.* Applied to automatic substations the foregoing considerations call for the elimination of refinements except those which improve the continuity or constancy of the electric service maintained at the various parts of the work.

There are, to be sure, many industrial applications in which the cost of electrical energy is a large part of the total cost of production, but these applications usually have high load factors, so that the efficiency of conversion is naturally high. Power economies in these cases can, therefore, be sought only through proper layout of the distribution system or through improvements in the technique of the industry itself. No less than in the industries discussed earlier, industries in this class require reliability of the substation above all else.

Character of Automatic Service Required

In our definition of automatic substation one of the essential elements is the maintenance of the "required character of service." From the economic considerations outlined it appears that the best service is provided by starting the required number of substations before operations begin and maintaining this service until the working period ends. A typical industrial automatic substation will be started at, say, 6:30 a.m. by pilot wires to a convenient point at a distance, will run continuously throughout the day, and will shut down at, say, 5 p.m. In other typical cases a substation will start automatically whenever the alternating-current incoming power is available and will not shut down at all (except on failure of alternating-current power or other emergencies in which the unit must be shut down for protection). Other provisions for putting the substation in and out of service may be made in accordance with other requirements determined by conditions under which the enterprise operates.

*It is recognized that close supervision of energy consumption may be important for a very different reason. An undue increase in energy consumption may indicate faulty conduct of the work or inadequate facilities which are causing losses greatly in excess of the increase in the power bill itself.

Benefits from A[illegible] Operation

[illegible] of attendants for con-[illegible] [illegible]titute a consider-able [illegible] cost of power serv-[illegible] were possible to accom-[illegible] the saving of these [illegible] item, particularly [illegible] be operated two or [illegible] In many cases the [illegible] take the form of a certain [illegible] ations at specified locations, either [illegible] automatic and attended, or auto-matic and unattended. Under these con-ditions the cost comparison is simply oper-ators' wages versus capital charges on the extra investment necessary for automatic operation. As will be discussed later, how-ever, automatic operation may improve the quality of the service to an extent having an actual financial value.

In other cases the wage situation takes on a broader aspect. In industrial operations extending over a considerable distance, e.g., some mines or steel plants, it may be desirable to use several single-unit substations dis-tributed over the property in order to improve the voltage regulation without an excessive installation of feeder copper. But since ordinary substations require operators, the wage item may dictate the use of a smaller number of substations than is best from the standpoint of distribution. The automatic substation removes this wage limitation so that the number and location of automatic substations may be determined solely with re-spect to distribution. Under some conditions the great reduction in feeder copper which this arrangement of automatic substations permits may more than cover the entire extra investment for the automatic substation equipments; thus (after deducting a small expense for inspection) there is a net saving of nearly the entire item of operators' wages and an additional saving of capital charges.

Quality of Service: Under this head may be included elements which have an effect, di-rectly or indirectly, on the profits or security of the enterprise but which are difficult to evaluate definitely in dollars.

The railway experience indicates that automatic substations operate with fewer interruptions than manually controlled sub-stations, and that wear and tear on the sub-station machines are reduced by the elimina-tion of unskillful handling.

In an operation containing several manual substations interconnected on the direct-cur-rent side and subject to loads which vary in magnitude and shift about on the system, a substation overloaded beyond its limit trips its direct-current circuit breaker and throws its entire load on the remaining substations. This, in an extreme case, may so heavily over-load the other substations that their direct-cur-rent circuit breakers open successively. Under more favorable conditions the remaining sub-stations will carry the overload, but feeding through a long distance with consequent excessive voltage drop to the loads which are causing the difficulty. On the contrary, the recommended form of automatic substa-tion for interconnection on the direct-current side has provision whereby a substation, when the load approaches its momentary capacity, limits its own load so that its direct-current circuit need not open. Thus it shifts only the excess to the other substations, but continues itself to deliver a moderate overload. This evidently provides the greatest practicable continuity of service, the best voltage at the working places, and the least slowing down of production during heavy overload demands.

Alternating-current Automatic Substations

The principal field for automatic sub-station control has been that of substations for conversion from alternating to direct current. The question is often asked: What are the possibilities of the automatic substa-tion for alternating-current industrial power? There is a large field for automatic control for public service alternating-current distribution, but within individual industrial plants the con-ditions are considerably different. In the aver-age industrial plant which is operated by alter-nating current the transformer substations are located advantageously for voltage regulation and feeder investment and the feeders are not particularly subject to troubles. These substa-tions usually are not attended but give entirely adequate service on this basis, so that under these conditions there is practically nothing for an automatic substation control to do. Where, however, an industrial plant must use trans-former substation operators, or is having difficulty or taking an appreciable risk due to operation without attendants, the possibility of automatic operation should be considered.

Synchronous condensers, being rotating machinery, should be either attended or con-trolled automatically. Applications of syn-chronous condensers have probably been limited by the problem of attendance, but the use of automatic control makes it practi-cable to locate condensers wherever in-herently most desirable.

Industrial Plant Substations

By E. G. Merrick and B. Nikiforoff
Power and Mining Engineering Department, General Electric Company

E. G. Merrick

FOR convenience of analysis, substations may be divided into two general classes, which we will designate as main and secondary. The former, which are usually located at important load centers, constitute an integral part of the main transmission system, receiving primary power direct from the system and distributing it to various points of consumption. The character and operation of their equipment must therefore be of the same order as that used in the balance of the primary system, so as to insure continuity of service from the generating station to the distribution feeders under both normal and transient conditions.

The secondary class covers substations which furnish power to individual consumers, such as industrial plants. They may be fed directly from the primary system or from a main substation, but in either case the selection of equipment is governed largely by the nature of the particular load, rather than by general distribution requirements. Here too, continuity of service is a desirable feature, but the degree sought after depends on the extent to which interruptions of power supply can be capitalized, and this will vary widely in different classes of plants.

B. Nikiforoff

Failures in modern, well-installed, and carefully operated electrical apparatus are very rare and recognition of this fact accounts for the simplicity of design in many secondary installations where temporary interruptions would not be serious. The possibility of failure must be recognized nevertheless, and this necessitates, in many cases, a greater outlay to obtain the quality of service desired and may result in a design comparable with that which would ordinarily be required for a main substation of the same capacity.

Several simplified one-line diagrams of substation connections have been included in this article and a brief analysis is given of each in order to illustrate more clearly the considerations governing the selection of different types of stations to meet various conditions. These are typical designs which must necessarily be modified to meet the requirements of particular cases. The illustrations chosen cover only plants whose operating voltage is lower than that of the feeder and which therefore require step-down transformers. Where the plant operates at feeder potential, the modification in arrangements will be evident.

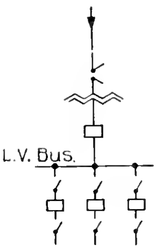


Fig. 1

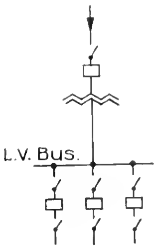


Fig. 2

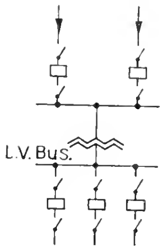
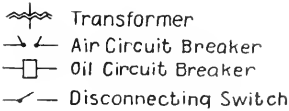


Fig. 3



[illegible] pe- [illegible] applica- [illegible] the end [illegible] plant [illegible] generator [illegible] der protect- [illegible] substation [illegible] cause will [illegible] substation. [illegible] switch might [illegible] tension breaker, [illegible] provides a safe [illegible] transformer bank [illegible] under certain emer- [illegible]

[illegible] mer and line can be [illegible] ly from the supply end of the feeder, the arrangement shown in Fig. 2 may become necessary, due to the limited amount of magnetizing current which can be safely handled by a high tension air break switch during high tension switching.

The equipment of Fig. 2 is also preferable to that of Fig. 1 when several substations are connected to the same feeder. In case of transformer failure in any station, the high tension transformer switch will open and therefore protect the other stations against interruption of service. No low tension transformer oil switch is required in this arrangement, as the high tension breaker provides a means of disconnecting the substations completely from the feeder. The possibility of total loss of power, due to line or transformer failure, is the same in this case as with the arrangement of Fig. 1.

In order to protect the service against interruptions due to line failure, double circuit feeders should be provided and equipped with power relays, in conjunction with overload relays at the supply end of the circuit, which will automatically cut off either line that may be in trouble, throwing the entire load on the other line, which should have sufficient capacity to carry the entire load temporarily without causing excessive line drop.

The scheme shown in Fig. 4 indicates a simple arrangement of a substation acting as a switching station. The two line breakers make possible the sectionalizing of the high tension line in case of line failure, permitting the substation to be fed from either side of the system without interruption.

Fig. 5 is an amplification of Fig. 3 by doubling the number of transformer banks. In case of transformer failure, the plant will be shut down temporarily, but as soon as the fault is cleared service can be resumed at partial output until the damaged transformer is replaced by a spare unit.

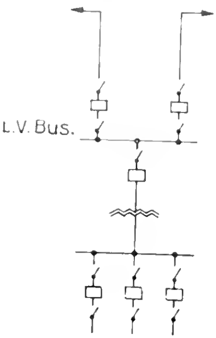


Fig. 4

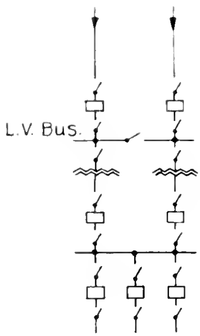


Fig. 5

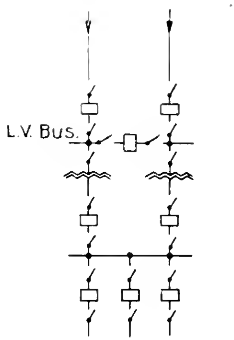


Fig. 6

The arrangement of Fig. 6 is somewhat more expensive than that of Fig. 5 due to the additional cost of the high tension bus-tie oil switch; the extra expense is frequently warranted, however, because of the gain in reliability and simplification of switching operations. In case of transformer failure differential transformer relay protection will open the low tension transformer switch, bus-tie switch and line switch corresponding to the bank in question and therefore automatically disconnect the faulty transformer bank. Under normal conditions, a transformer bank can be taken out of service by opening the bus-tie switch and the line switch corresponding to the transformer bank thus breaking the load current; the magnetizing current will then be broken by opening the low tension transformer switch.

A still more elaborate design is indicated in Fig. 7. With three or more transformer banks installed, it becomes necessary to add high tension transformer oil switches to secure automatic protection against interruption due to transformer failure. By the addition of differential transformer protection, the high and low tension breakers are made non automatic as regards external disturbanc but automatic in case of breakdown in the transformer windings or at the terminals. The great advantage of this method of protection lies in its sensitiveness and also in the elimination of a time differential between the high and low tension busses. The system can therefore be relayed as if the incoming feeders were connected directly to the low tension bus.

Additional reliability and flexibility are obtained by the installation of either double high or low tension busses, or both, as shown in Fig. 8. This provides a means of taking a bus out of service at any time for inspection or cleaning, and also of dividing the load for independent operation from separate busses.

Carrying the scheme of Fig. 8 still further, double oil switches may be used in both feeder and transformer connections. This removes any limitation to service which might be caused by an oil switch failure or by disconnecting a switch for inspection and cleaning.

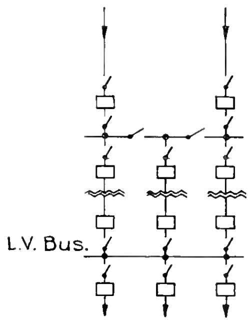


Fig. 7

The various substation arrangements which have been presented show the possibility in certain cases of reducing the cost of installation by substituting disconnecting or air break switches for oil switches where such substitution does not offer a serious handicap to the quality of service. Fig. 9 shows a photograph of an air break switch such as might be used for the equipment shown in Fig. 1. This type of switch has successfully broken charging and load currents corresponding to approximately 3,600 kv-a; under different operating conditions this value might have been increased or decreased, depending on the switch spacing and the magnitude and direction of the wind. For moderate voltages, the switch can be built in combination with

Fig 9 70,000-volt Outdoor Air Circuit Breaker

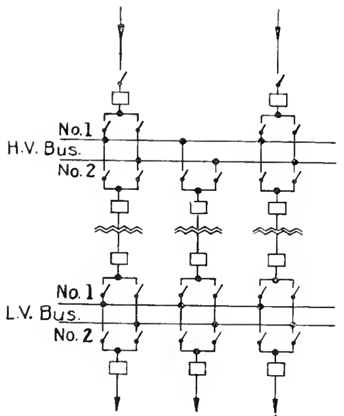


Fig. 8

[illegible] ...s, all mounted on a [illegible] ...entially an outdoor [illegible] ...n necessary for [illegible] ...ily provided for [illegible] The construction [illegible] ...le mounting.

[illegible] ...red, in some cases, for [illegible] ...eir application is rather limited. Under heavy short circuits selective action between fuses of different capacities is unreliable. The delay in reestablishing service may also be prohibitive.

Fig. 10. Oil Fuse Cutout

A comparatively recent development in fuses for voltages below 15,000 volts is shown in Fig. 10. The fuse is submerged in oil in a cast iron tank. These fuses have a considerable rupturing capacity, viz., 10 times normal current for the light type and 25 times normal current for the heavy duty type. The construction permits of easy replacement of the fuses.

In selecting transformers for substations, a choice must be made between three-phase and single-phase units of self-cooled, water-cooled, forced-oil or forced-draft type. The selection will usually be decided on the basis of first cost, including spare equipment, efficiency, space limitations, weight to be handled, availability of cooling water, and cost of operation. For general substation use, the single phase, oil-cooled unit will probably have the widest application, but consideration of the different items just mentioned will often lead to the selection of one of the other types in particular cases.

Modern substation design is strongly in favor of outdoor installations. This applies particularly to high tension equipment, including lightning arresters, disconnecting switches, oil switches, power and metering transformers and high tension busses. The control and low tension equipment only are installed indoors and the saving in building cost is ordinarily a considerable item. The outdoor station also lends itself more readily to future extensions. The reliability of outdoor apparatus has been so thoroughly established that no hesitancy is now felt in recommending its use under the most severe climatic conditions. Figs. 11 and 12 illustrate typical outdoor equipments for stations of widely different capacities.

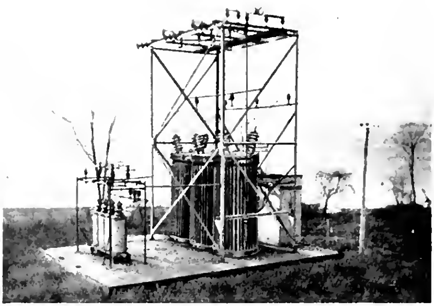


Fig. 11 Small Outdoor Substation

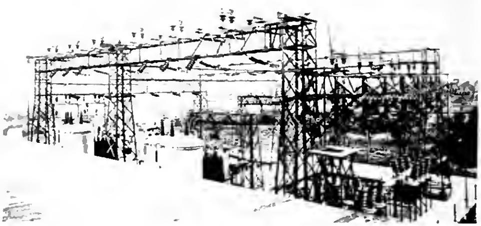


Fig. 12. Outdoor Substation of Large Capacity

Space limitations have permitted touching but briefly on some of the salient features of substation design. These and other features must be carefully considered by the industrial concern which is contemplating the purchase of power as the selection of proper equipment for any particular installation has an important bearing on reliable and economical plant operation.

Load Equalization

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F. L. Stone

The most efficient way of handling peak loads, both from the power house and the consumer's standpoint, has always been a serious problem. The power house question is, "What shall we charge for peaks of short duration above the average load?" The consumer's question, "How much can I afford to pay for these peaks?" In most communities the power rate is fixed by the public service commission and usually involves a peak clause; this clause, however, may be of such a nature that the instantaneous peak does not in any way affect the rate.

For example, the demand charge may be based upon the maximum 5 or 10 minute or even longer integrated peak, and the kw-hrs. charge made in a separate item. Then again, the demand rate may be based upon an integrated time peak and the consumer allowed to exceed this average for very short times by a given amount, but any excess of this amount, or some portion of it, will be added to the integrated peak to determine the demand charge. Whenever instantaneous peak is referred to in a power contract the consumer should be very sure he knows what the nature of his load is to be, and how this instantaneous peak is going to affect his power bill.

T. W. Kennedy

The mining industry affords the best example of variable loads and poor load factor. The underground mine load is made up of pumps, ventilating fans, locomotive haulage, rope haulage hoists, cutting machines, and various and sundry small motors for many uses differing in different localities.

The surface load is made up of tipple and breaker machinery and occasionally some haulage. Of these loads the haulages and hoists are very intermittent and usually produce excessive peaks.

Fig. 1 shows a curve taken from a 24-hour chart of a power house feeding a group of mines. The total connected horse power in

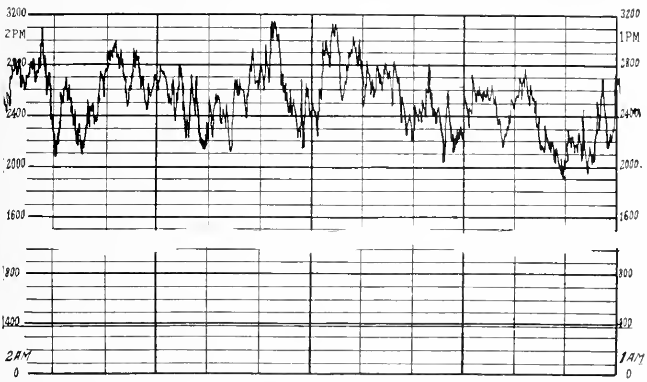


Fig. 1. Sample Kilowatt Time Curves from Power House Supplying Five Mines
No Main Hoists Connected

[illegible] low [illegible] Loco motor [illegible] hp. pumps, 240 [illegible] a power [illegible] of the [illegible] load factor.

The pumps and fans as a rule operate at a fairly high load factor, while the haulages and hoists on the other hand operate at very low load factor.

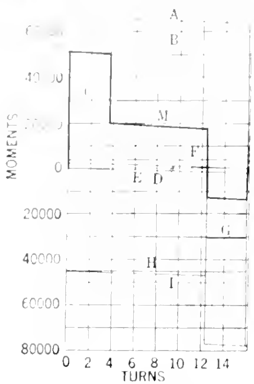


Fig. 2a Moment Diagram Case I Single Cylindrical Drum—WR Rotating Parts 200,000

A = Total moment up load
B = Moment up cage car and ore
C = Acceleration moment
D = Up rope moment
E = Down rope moment
F = Friction moment
G = Retardation moment
H = Drum cage and car moment
I = Total down moment
M = Total net moment

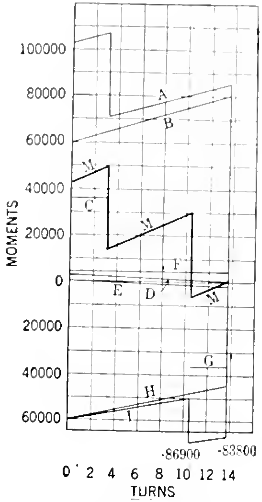


Fig. 3a. Moment Diagram Case II—Conical Drum 6 ft. to 8 ft.—WR² Rotating Parts 300,000

A = Moment up load, total
B = Moment up car, cage and ore
C = Moment acceleration
D = Moment up rope
E = Moment down rope
F = Moment friction
G = Moment retardation
H = Moment down car and cage
I = Moment total down side
M = Moment total net

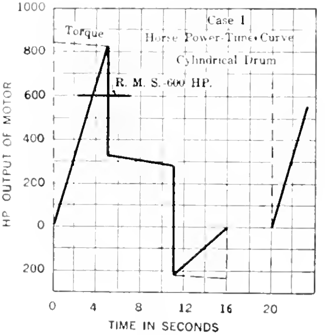


Fig. 2b

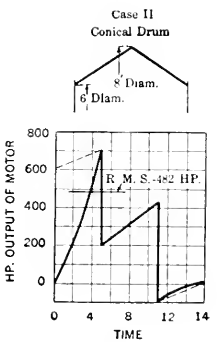


Fig. 3b

The hoists if they are of any considerable size produce the highest peaks and are the most intermittent in service. For instance, a hoist making three trips per minute must start and stop three times per minute, the load increasing from zero to as much as double load in five seconds, and back to zero in 10 seconds more.

There are numerous ways of compensating for, or removing this peak from the line. If the peak is not too excessive, the design of the drum should be given serious thought. Below is shown the resulting duty cycle where various shapes of drums are used for the same production.

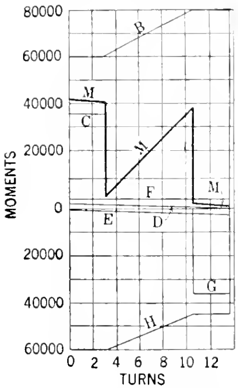


Fig. 4a. Moment Diagram Case III Cylindro-Conical Drums 6 ft. to 8 ft.—WR: Rotating Parts 300,000

B = Moment up car, cage and ore
C = Moment acceleration
D = Moment up rope
E = Moment down rope
F = Moment friction
G = Moment retardation
H = Moment down cage and car
M = Total net moment

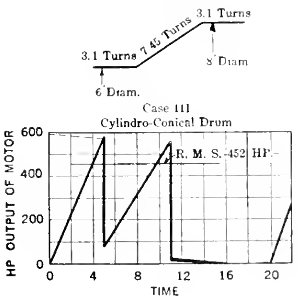


Fig. 4b

Duty cycle in each case made up from the following data:

Weight of coal hoisted....	5000 lb.
Total lift	300 ft.
Weight of cage.	11,000 lb.
Weight of car	4000 lb.
Rope ...	1.25 in.
Number of trips per min.	3
Rest between trips...	4 sec.

Case 1. Cylindrical drum.
Case 2. Conical drum.
Case 3. Cylindro-conical drum.

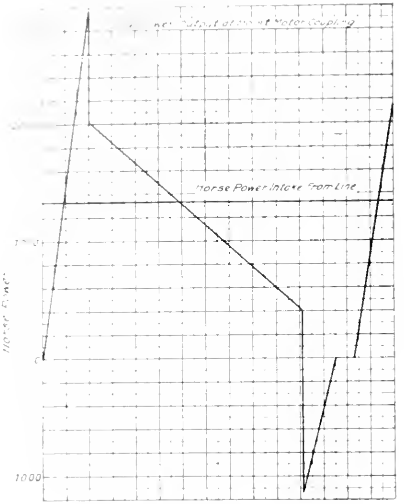
By examining the moment diagrams of Figs. 2a, 3a, and 4a and the horse-power output of the motor in each of the three cases, it will be seen that the accelerating peak is quite materially affected. Case 1 shows an acceleration peak of 825 h.p. In Case 2, that of a conical drum, the accelerating peak is reduced to approximately 700 h.p.; while in Case 3 we have reduced the accelerating peak to approximately 600 h.p.

The drum shape can be of great help in many cases, but is by no means the answer for all problems. Drums of odd shapes get very heavy and thereby defeat the object for which they are intended.

In case the peak cannot be reduced sufficiently by the use of odd shaped drums, the only solution left is the utilization of some device which will store up energy when the demand is low and give it up when the demand is high. There are several means of accomplishing this that are known to the art, such as storage batteries, compressed air, etc., but the most practical method seems to be the use of a flywheel.

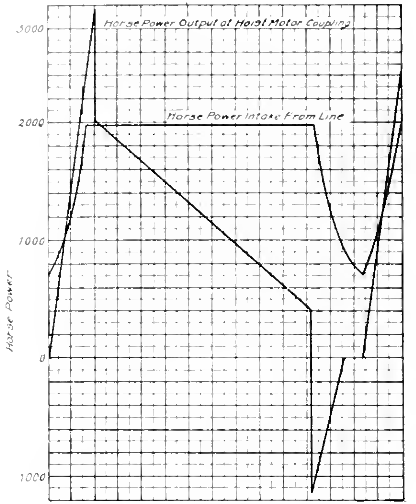
The most satisfactory way of using a flywheel is in combination with a motor-generator consisting of an induction motor connected mechanically to a d-c. generator and a flywheel. The hoist motor is driven from the d-c. generator and controlled by the well-known Ward-Leonard control. The secondary of the induction motor has a variable resistance connected across the collector rings and controlled by the line current. When the current tends to increase above a predetermined value the resistance increases, tending to hold the current constant; and vice versa, when the current falls the resistance decreases, tending to keep up the current. This action necessitates a change in speed of the motor, and the wheel will give out energy and absorb energy as the speed [illegible] the arrangement [illegible] Ward-Leonard system [illegible] modifications of [illegible] the same general [illegible] generally understood. [illegible] mind that it is not [illegible] completely equalize the [illegible] necessary to pick off

and the Ward-Leonard hoist with flywheel. Size has little to do with the matter. If the cycle is rapid, say three trips per minute, and the depth 300 ft. or more, the Ward-Leonard system would be so much more economical in power consumption that its large first cost in all probability would be warranted by the saving in power consumption. Each case must be treated separately



Time

Fig. 5



Time

Fig. 6

In the approximate horsepower-time diagrams, Fig. 5 shows total equalization and Fig. 6 the approximate input to the motor for partial equalization. The latter involves a much lighter wheel and could be accomplished by notchback relays in place of the liquid rheostat or liquid slip regulator as it is often called.

The question is asked many times where the dividing line as to horse power comes between the ordinary induction motor hoist and in order to arrive at a dependable answer facts must be dealt with, not guesses.

The power rate must be known; also the depth, the load, the weight of all moving parts, etc.; and finally the other loads which are to be metered out at the same point. With these facts at hand it should not be difficult to predict with reasonable accuracy just how the power bill will be affected by a peak of short duration.

Load Equalization as Affecting Power Rates

By L. A. Umansky

Power and Mining Engineering Department, General Electric Company

L. A. Umansky

It is a well recognized fact that an up-to-date power rate schedule should consider not only the integrated amount of energy consumed at a given service connection but should take into account the character of the load. Quite evidently a steady and constant load of, say, 500 kw. for 24 hours a day requires less installed capacity at the generating station than an intermittent load of the same integrated value but which includes high peak demands amounting to, say, 1500 kw.

In the case of an isolated power plant a load of the latter character may require a large increase in the installed generating capacity with a respective increase in the fixed capital charges, which can but raise the cost of electric power for the producer and therefore for the consumer. If, on the other hand, a large distribution system is considered the heavily fluctuating load at a service connection increases the fixed charges not so much by requiring additional installed capacity at the generating plant, as by necessitating larger substations, feeders, etc.

In either case the customer should be expected to pay directly or indirectly the primary charge for the "readiness-to-serve" determined by his maximum demand, besides paying for the amount of energy actually consumed. The purpose of this article is to illustrate the magnitude of the extra charges added to the power bills, and the importance to the customer of using suitable means of reducing his maximum demands.

Although the actual primary charge is necessarily higher in the case of an isolated plant, it is better to illustrate the case as applied to the rates of a large power system. These rates are based on average conditions prevailing in a number of installations and the results thus obtained should therefore be considered the more convincing.

Mining companies which use electric hoists comprise a large class of customers that pay penalty rates for high peaks, and thus it is well to take a mining load cycle as a good illustration.

Fig. 1 gives an idea of the typical load curve drawn by the recording meter installed by the power company at a mining service connection.

One large eastern power company with many coal mines as customers defines its rates in the following manner:

First of all, the so-called "significant peak," S, of a given service connection is determined. For this purpose a maximum five-minute average load for the given billing period is selected from the record chart of the curve-drawing meter. This corresponds to value A, Fig. 1. If during the same billing period the actual maximum demand did not exceed for any moment 150 per cent of the foregoing five-minute average, then the latter is considered as the "significant peak." If, however, the peak P exceeded the 150 per cent limit, half of the excess should be added to

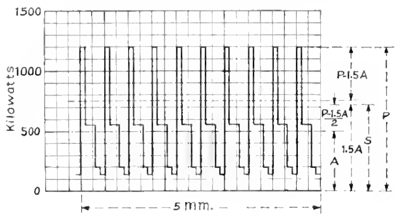


Fig. 1

the five-minute average and the total is then defined as the "significant peak." In other words, whenever P is greater than $1.5A$:

$$S = A + \frac{P - 1.5A}{2} \text{kw.} \qquad (1)$$

or

$$S = \frac{P}{2} + \frac{A}{4} \text{kw.} \qquad (2)$$

In case of lagging power-factor ($Cos\ \phi$):

$$S = \frac{1}{Cos\ \phi} \times \left\{ \frac{P}{2} + \frac{A}{4} \right\} \text{kw.} \qquad (3)$$

It is then assumed that the customer has used this power for 70 hours a month, and he is charged for this fictitious amount of energy at the rate of six cents per kilowatt-hour.

This constitutes the primary charge. The balance between the actual kilowatt hours consumed (according to the kilowatt-hour meter readings) and the fictitious amount of energy as defined (70×S) kw-hr., is charged at the rate of only 1.25 cents.

Let us assume that the duty cycle as represented by Fig. 4 has a five-minute average of A = 500 kw. and a maximum peak of 1200 kw. Considering for the simplicity of discussion a unity power-factor, the significant peak will be determined from equation (2)

$$S = \frac{1200}{2} + \frac{500}{4} = 725 \text{ kw.}$$

The fictitious energy as defined will be $70 \times 725 = 50{,}750$ kw-hrs. The primary charge will then be, regardless of kilowatt-hour-meter readings:

$$50{,}750 \times 0.06 = \$3045.00$$

In case the mine operates at the same rate for eight hours a day, or two hundred hours a month, the total actual energy consumption will be $500 \times 200 = 100{,}000$ kw-hr. The secondary charge will amount to

$$(100{,}000 - 50{,}750) \times 0.0125 = \$615.60$$

The gross total will be

$$3045 + 615.6 = \$3660.60$$

If, on the other hand, the maximum peak were reduced to 750 kw., i.e., to 150 per cent of the five-minute average demand, the monthly bill calculated in the same manner would amount to only \$2912.50. This represents a monthly saving of \$748.10, or a power bill reduction of 20.5 per cent.

Other power companies define and calculate the primary charge in somewhat different ways, but any of the modern power rate schedules if applied to the foregoing example will illustrate just as clearly how much the customer has to pay in excess charges for not applying some of the numerous means of reducing the load peaks. The yearly saving in the amount of bills will not only cover the capital charge against the load equalizing apparatus, if any, but in numerous cases enough will be left over to represent a handsome return on the invested money.

When we speak of load equalization, we do not necessarily mean a complete equalization, resulting in a constant input to the power apparatus. In a good many cases all that is required is the lowering of those peaks which are in excess of the permissible values, as defined by the power rate schedule or by the generating capacity of the power plant. In the example under discussion, the elimination of the peaks which do not exceed 150 per cent of the maximum five-minute average load will not reduce the power bill and cannot therefore be considered as a paying proposition for the customer, as long as the rate schedule is unchanged.

For the same reason any peak higher than 150 per cent value should not be necessarily reduced much below the 150 per cent mark.

In the case of mine hoist load, surprisingly gratifying results may be obtained by using conical or cylindro-conical drums of proper shape instead of cylindrical drums. This point is well illustrated by duty cycle curves presented in the article by F. L. Stone and T. W. Kennedy in this issue.

When these means cannot be very well adopted for various reasons, the engineers can apply a method using flywheels in connection with the electrical machinery. Whenever the load curve has a periodical shape, that is, the peaks alternate regularly with points of low demand, the combination of properly selected flywheel masses with well designed electrical equipment will give the desired results. The widely known flywheel motor-generator sets are but one of the several feasible arrangements of that nature for the elimination of high peaks.

The description of the technical features of load equalizing apparatus is outside the scope of the present article, but it is quite obvious that there is a good economic reason not to spare any engineering effort to study thoroughly each individual problem and to find for each a solution which will give the customer the best operating efficiency.

Power Contracts and Substations for Industrial Loads

By Ernest Pragst and A. G. Darling
Power and Mining Engineering Department, General Electric Company

Ernest Pragst

Wherever an industrial plant is built the engineer, entrusted with providing the means for meeting the particular industry's power requirements, is invariably confronted with the important question: Shall we install our own generating station or purchase power from the local public utility?

In a great proportion of cases, particularly the large power using industries, the question can not be answered off-hand. A comprehensive study of the problem is often required and should be welcomed by the utility seeking the load; for to prosper in its service to this class of customer the utility must be in a position to render a more reliable and cheaper service than it is possible to obtain in an isolated plant operated by the industry. Such a study usually involves an investigation to ascertain the class of service the utility is in a position to render, and the cost of this service to meet the particular load requirements of the industry. A contrast should then be made between the cost of this purchased energy plus the cost of operating a low pressure steam heating plant for process and building heating and the cost of operating an isolated station and heating plant, crediting the cost of power generation with that part of the prime mover exhaust steam which it is possible to utilize in the heating system.

Assuming that the results of such an investigation indicate the economic desirability of purchasing power, what are the provisions that should be made for its receipt and distribution?

Size of Substation

Knowing the energy requirements of the various power using pieces of apparatus throughout the plant and applying a diversity factor which experience in the particular class of industry suggests, we arrive at an estimate of the possible peak load that must be provided for by the power company and industrial plant—in generating and transmission capacity by the former, and in transportation, conversion, and distribution capacity by the latter.

A. G. Darling

Experience with this class of industrial application leads us to conclude that engineers responsible for the design may be more justly criticised for a lack of optimism in the success of the particular industrial venture than for any degree of over optimism, which is so often a characteristic displayed by men engaged in other activities. An initial installation should not be made simply to meet immediate requirements; rather, we should attempt to anticipate the extent and nature of the probable plant growth which is the usual result of successful operation and provide for it. The initial installation should provide adequately for the immediate plant activities, and should be so designed that extensions may be made conveniently from time to time as demanded without having these extensions handicapped as a result of a near-sighted policy in the original design.

Power Contract

Most modern power contracts are based upon furnishing energy in the form of three-phase alternating current at the standard distribution potential of the central station. In some cases the customer owns and operates the complete substation with its transforming apparatus, etc. In other cases the power company owns the necessary transforming apparatus, and usually reaches an agreement with the customer upon a low tension potential suitable for plant distribution, thereby reducing the transformer capacity to a minimum. In the former case the metering of the power is usually done on the high tension side of the substation transformers, the customer paying for all transformer losses; in the latter case, it is customary to meter on the low tension side, the losses being borne by the power company, which must also maintain and carry the fixed charges on this part of the installation at the industrial p[illegible] [illegible]ation. Obviously the remunerat[illegible] [illegible]e power company in the latter ca[illegible] [illegible]exceed that in the former by a[illegible] [illegible]cient to cover this additiona[illegible]

A[illegible] contract should also specify [illegible] frequency and potential which it [illegible] to hold at the customer's substation, and the maximum variation above and below this normal which it is understood the power company will not exceed, providing, of course, the customer does not exceed the limits of load for which he has contracted. It is also desirable that the contract mention the normal power factor of the load during times of customer's maximum demand or loads approaching it, with a graded penalty for failure to meet this power factor and a corresponding bonus for a power factor exceeding the specified normal. After assuring the prompt payment of the monthly bill, there is perhaps no clause of a power contract which will better pay the power company than one which will induce the customer to maintain a high power-factor during periods of heavy load.

The charge for central station service to the more important classes of loads, where the remuneration compensates for the more complicated method of metering, is now usually based upon two characteristics of the load—the maximum demand and the energy consumed during the period for which the bill is computed. The maximum demand charge, usually expressed in kilowatts, is based upon the fixed charges and maintenance of the investment made by the power company in generating, transmission, and distribution apparatus which must be held, maintained and operated by the utility to meet the power demand of the industrial plant. The energy charge, universally expressed in kilowatt-hours, is a charge based upon the cost of fuel in steam generating stations, or water and water storage reservoirs if employed in hydro-electric stations, plus the cost of handling, to supply the requirements of the load. Sometimes the demand charge decreases with an increase in demand, and usually the energy charge decreases with an increase in consumption. This method of rate making has come into general favor. It is applicable to all classes of power service, with the possible exception of some special forms of off-peak and seasonal types of load.

Continuity of Service

Continuity of service to an industrial customer is essential. In certain industries an interruption in service results in only a loss of production and labor during the time of interruption; in other industries such an interruption would result, in addition to this loss, in a depreciation or even total loss of the material in the process of manufacture at the time. Naturally, any provision which it may be practicable to make to assure any particular degree of continuity of service is to a large extent a function of the rate charged for service, the investment involved, and the extent of the load. In a great many cases the income derived from a given service justifies only the simplest form of construction—a single incoming circuit, fuses, transformers, and metering equipment. In other cases, particularly those involving large important loads, it is often possible to deliver and meter the power with some such simple means; but in such cases the assurance of continuity of service is not very great, particularly if the line feeding the load is long and subject to lightning disturbances. Very often it is possible, with the cooperation of the customer, to decrease the chance of serious interruption at but small additional expense for equipment, by careful design, thereby avoiding financial loss to both parties and the sacrifice of good will and confidence of the customer.

It should be remembered that in most energy consuming industrial processes, except perhaps the electro-chemical and electro-thermal industries, where the energy is utilized in the form of mechanical power the cost of power represents but a small part of the total cost of the product. Labor and material are the principal items. As a rule the power cost does not exceed five per cent of the cost of the product, and in the majority of cases it is, perhaps, nearer two per cent.

When we consider that the cost of power to most industries represents but a small part of the cost of the manufactured product, that is, but a trifle when compared with labor, raw materials, fixed charges, etc., and that when it fails production ceases, we are forced to conclude that the central station must employ every reasonable means to assure continuity of service, and that the industry can afford and should pay an amount sufficient to warrant the installation and maintenance of such apparatus as is essential for rendering the highest class of service.

The selection of liberally designed apparatus, duplicate service feeders, adequate lightning protection, a properly chosen selective relay scheme, close attention to design and installation details, and careful operation and intelligent supervision over operation are the essential factors for securing a high standard of service.

Short-circuit Currents

It is needless to comment upon the mechanical stresses, heating, and extremely severe duty generally which short circuits on modern central station systems impose upon circuit breakers, buses, cables, etc., unless provision is made to limit their effects. The magnitude of these possible short circuit currents is usually limited to a safe value by the segregation of apparatus, the introduction of reactance, etc.

The interests of the power company should extend beyond the limits of the apparatus forming its system, to include its customer's plant, particularly with regard to the possible effects of short circuits within his system. Very often circuit breakers have been selected for industrial plants which were of ample capacity to rupture any short circuit which might have occurred at the time the installation was originally made, but owing to the rearrangement of the distribution system or to a rapid increase in central station generating capacity the breakers have become inadequate within a short time. It is not uncommon to find circuit breakers installed in industrial plants controlling circuits where the possible values of short circuit currents exceed by several times the safe rupturing capacity for which the circuit breakers have been designed. As a rule, when the initial installation of the industrial plant is made the apparatus is properly chosen to meet the requirements then obtaining. It is the unforeseen growth of load, the rapid increase in capacity of generating and distribution systems and lack of foresight that are usually the causes of this condition. There are cases where the increase in possible short circuit current has been so rapid that circuit breakers which were adequate at the time of placing the order for equipment were entirely inadequate before the installation could be put in operation. When negotiating a new power contract with an industry, a definite statement by the engineers of the power company to the power customer relative to the possible magnitude of short circuits is highly desirable. There should be a further understanding to the effect that the power company will undertake to limit the maximum possible short circuit current to a specified value for a definite period of years. With such an understanding by both parties,the installat on can be carried out with the assurance that it will be safe as regards the effects of short circuits for at least the period of agreement.

Limiting the Maximum Demand

The demand and energy charges of a well balanced power contract should be such that the revenue to the power company represents a reasonable return over and above the expense of serving the customer, irrespective of the load-factor of the particular load. The engineers of the power company can suggest means and assist the customer in selecting apparatus and working out methods of reducing the demand without materially reducing the per cent earnings of the utility which may result in the further extension of service. Any decrease in demand for the same energy consumption by a given customer wi l result in a definite saving to the customer and a decrease in the cost of power per unit of energy consumed. It will not particularly lessen the revenue of the power company, because it will make available apparatus and line capacity for meeting the demand of other customers.

Power-factor Correction

The credit to be given power customers for maintaining a power-factor equal to or higher than the normal specified in the power contract should be ample to justify and encourage any reasonable expense that the customer might be put to in securing the higher power-factor. As a rule, this high power-factor is essential to the power company only during the hours of heavy load. It is equally true that it might be costly and inconvenient to the customer to maintain a high power-factor during periods of light load as well. For example, a customer might feel justified in purchasing and operating a synchronous condenser ten hours a day, six days a week, in which case he would pay for the power losses of the condenser for only 60 hours out of a possible 168 hours per week. If the power contract does not specify the time nor load at which the high power-factor must be maintained it may be inferred that it should be at all times. In such case the power company must reimburse the customer for the power consumed in the corrective apparatus based upon its continuous operation, thus reducing the possible revenue unnecessarily by the amount which is necessary to pay for the energy losses of the condenser during the off-peak period, when its operation is not essential to proper voltage regulation nor to reducing the reactive kv-a. of the system.

The engineers of the public utility can here also exercise their influence and experience in maintaining a high power-factor to the mutual benefit of their company and the customer, particularly by guarding against the over-motoring of machines driven by induction motors and by insisting on the installation of synchronous motors in all cases where a synchronous motor drive is possible.

Co-operation

A public utility engaged in supplying electrical energy to any industrial plant, or in performing any other service for that matter, must conduct its business on the basis of furnishing to its customers a superior service for less money than can be obtained in any other manner. It must convince its customers that it is doing this; it must seek and maintain their good will, confidence and co-operation. It is essential that the customer shall appreciate the fact that the utility is rendering him a service the equal of which he can not duplicate, and that for this utility to endure it must receive a fair compensation for the service rendered. Just as the utility is dependent upon the success of its customers' undertakings for its own success, so also is the success of the customers of the utility to some extent linked with the fortunes of the utility. Through a spirit of close co-operation and mutual interest, mutual benefits should accrue to both parties to a power contract.

The Electric Melting Furnace as a Central Station Load

By H. A. Winne

Power and Mining Engineering Department, General Electric Company

H. A. Winne

When electric furnaces for the melting of steel and other metals first came into use, the majority of power generating companies were rather afraid to take a furnace load on their lines, and this antipathy still persists to a certain extent. As a matter of fact, an electric furnace, when properly installed and operated, is usually a desirable type of load for a central station.

That the electric furnace has come to stay there can be no question, and it is equally certain that the number of furnaces, and the power required to operate them are going to increase enormously. We have only to consider the phenomenal strides made by the electric furnace industry in the past decade to have these facts impressed upon us.

Take, for example, the electric steel furnace. In 1911 there were only about ten electric steel furnaces in operation in the United States, and the steel produced in them amounted to 29,105 tons. By 1915 the number of furnaces had increased to 41, and the production of electric steel to 69,412 tons. In 1917 there were in operation some 136 furnaces producing 304,543 tons of steel. By 1919 the furnaces numbered 287, and the output was 566,084 tons. On January 1, 1921, 356 electric steel furnaces were installed or contracted for in the United States. Translating the foregoing into terms of installed kilovolt-ampere capacity, and yearly power consumption, we have the figures given in Table I.

TABLE I

TOTAL CAPACITY AND POWER CONSUMPTION OF ELECTRIC STEEL FURNACES

Year	Estimated Total Installed Kv-a. Capacity	Estimated Total Annual Kw-hr. Power Consumption
1911	5,000	22,000,000
1915	25,000	45,000,000
1917	100,000	155,000,000
1919	240,000	260,000,000
1921	320,000	

Estimating from these data as a basis, it seems reasonable to believe that in 1925, assuming a normal growth, the total transformer capacity of electric steel furnaces installed will reach 450,000 kv-a., and that the power consumed by them will total at least 500,000,000 kw-hrs. annually.

The development of the electric furnace for melting non-ferrous metals, such as brass, bronze, copper, and aluminum, is still more recent than that of the steel furnace, but it has already outdistanced its forerunner in point of number of furnaces installed, although not in total kilovolt-ampere capacity, nor in amount of power consumed. On July 1, 1915, so far as is known to the author, there was not a single electric brass melting furnace installed in the United States. On March 1, 1920, there were installed or contracted for 268 electric furnaces for melting non-ferrous metals. By March 1, 1921, this number had increased to 409, with a total transformer capacity of approximately 46,000 kv-a.

No figures are available as to the amount of brass and copper melted in electric furnaces, nor as to the total power consumption. However, with normal business conditions, the power consumed by non-ferrous metal melting furnaces in the present year would undoubtedly exceed 50,000,000 kw-hr. The amount of brass and other alloys melted electrically is certain to increase with extreme rapidity. The economies and advantages of the electric non-ferrous furnaces are so marked that their adoption by the major portion of the industry cannot be long delayed. It seems entirely possible that by 1925 the annual power consumption of these furnaces may total 350,000,000 kw-hr.

Here, then, including both the steel and brass furnaces, is a load which at present has a probable normal power consumption of 400,000,000 kw-hr. annually, and which by 1925 will have doubled this figure at least. What are the characteristics of this load? How does it compare with the ordinary power load? Is it a desirable load for a central station?

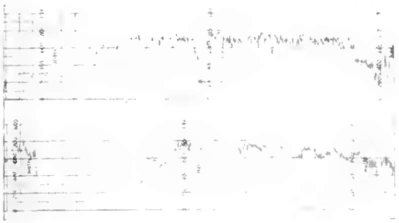


Fig. 1. Curve Drawing Wattmeter Records of Power Input to 10-ton Electric Steel Furnace (Melting and Refining) Controlled by Automatic Regulator

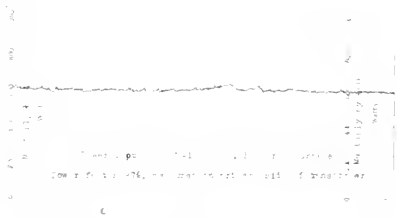


Fig. 2. Curve Drawing Wattmeter Record of Power Input to 1500-lb. Muffled Arc Brass Melting Furnace

In attempting to answer these questions the steel furnace will first be considered. Practically all electric steel furnaces, at present in operation in this country, are of the arc type.

Almost all types of arc furnaces can be made for operation from either single or polyphase circuits, but practically all steel furnaces now being installed use polyphase power. In the early days of the electric furnace, a number of single-phase units of comparatively small capacity were put into use and are still in service. On January 1, 1921, there were approximately 37 single-phase furnaces installed or sold, as against 319 polyphase units. Since January 1, 1918, so far as can be learned, only five single-phase steel furnaces have been installed in this country.

The average kilovolt-ampere capacity, that is, the transformer rating of the steel furnaces now installed, is approximately 900 each. There are some 144 installations with a capacity of 1000 kv-a. or over each, of which 15 are over 2000 kv-a. The largest units are of approximately 3000 kv-a. each. This leaves over 200 furnaces with capacities ranging from 50 to 999 kv-a. each. Furnaces which have been installed in the past two years will probably average somewhat higher than 900 kv-a., as the general tendency is to increase the ratio of transformer capacity to tons holding capacity, thereby permitting a greater tonnage output from a unit of a given hearth capacity.

Practically all polyphase steel furnaces now installed are equipped with some form of automatic electrode regulator. These regulators ordinarily consist of contact-making ammeters which operate in response to variations in the currents in the electrode circuits, and control direct-current motors, thro[illegible] [illegible] or contactors. When [illegible] operates, these motors [illegible] trodes, thereby lengthen[illegible] the arcs, and reducing or [illegible] currents. These regu[illegible] developed to a high degree

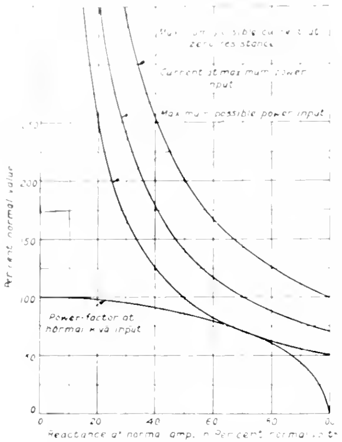


Fig. 3. Characteristics of Furnace Circuit as Determined by Amount of Reactance

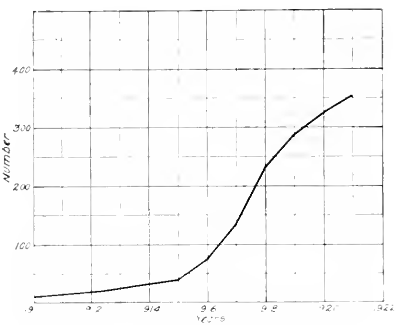


Fig. 4. Number of Electric Steel Furnaces in the United States

of perfection, and no arc furnace which is not equipped with one should be installed. It is safe to say that the automatic regulator has done more to make the electric steel furnace a desirable central station load than any other development.

But, as with all governing devices, the disturbance must occur before the regulator can correct for it. That is, the regulator cannot foresee disturbances that are about to happen in the furnace, and adjust the electrodes to prevent them. It can only pull the electrodes out of trouble after they have got into it. The reactance of the circuit must be depended upon to limit the value of the current surges that may occur during the melting down portion of the operating cycle. These surges may be due to pieces of metal falling against the electrodes and causing momentary short circuits, or to establishing the arc, after it has been broken by the rapid melting away of the metal. The frequency and duration of these peaks depend largely on the care used by the operator in charging the furnace. If the furnace is charged with heavy scrap entirely, or with fine scrap on the bottom and heavy on top, the fluctuations will be much more severe, and persist over a much longer period than if the heavy scrap is placed on the bottom of the furnace, with the light scrap and turnings on top. During the refining period, or in furnaces which work solely on molten metal, current surges are very much less frequent and severe than during the melting operation.

The percentage reactance in a furnace circuit will depend upon the amount of reactance inherent in the transformer, the arrangement of the conductors between transformer and furnace, the voltage and frequency at which the furnace operates, the kilovolt-ampere capacity of the equipment, and the reactance of external reactance coils if such are used. On very large, heavy current furnaces

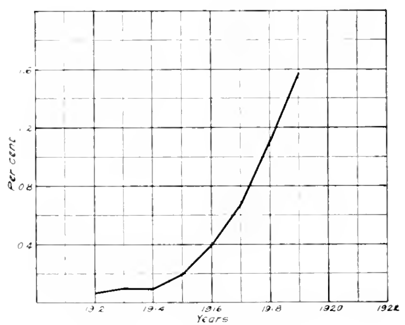


Fig. 5. Electric Steel Output in Per Cent of Total Steel Output of the United States

it is difficult to arrange the conductors to give sufficiently low reactance, and external reactance coils or high reactance transformers are rarely necessary. On the other hand, in units of small capacity, especially if they operate at comparatively high voltages, high reactance transformers and external reactance coils are often necessary to limit the maximum surges to a reasonable percentage above normal.

The most desirable amount of reactance for a given installation will depend upon local conditions. The higher the ratio of the furnace load to the total load in the station which supplies it, the greater should be the percentage reactance. However, it must not be too high, otherwise the operating power-factor will be too low. Fortunately, even with 50 per cent reactance, which would limit the maximum possible current surges to twice normal, the power-factor at full kilovolt-ampere load would be as high as 86 per cent. It is not usually wise to increase the reactance purposely beyond this point, as it will then limit the maximum possible kilowatt input to a value below the kilovolt-ampere rating of the transformer. On the majority of furnaces now in operation the total reactance ranges from 30 to 50 per cent, limiting the maximum current surges to from 333 to 200 per cent normal, and giving power-factors at normal kilovolt-amperes of from 95 to 86 per cent.

The operating cycle of a steel furnace varies according to the work being done. A furnace used solely for refining molten metal may operate at practically constant load for an hour or two, followed by no load during the pouring and charging period. The interval between heats may be from fifteen minutes to several hours. Such furnaces are usually operated day and night. In furnaces melting cold scrap and refining the metal, the length of a heat varies from three to six hours. During the melting period, of from two to four hours, the rate of power input usually averages close to the transformer capacity. During the refining period the input may be from one-third to two-thirds the rated value. The time between heats is ordinarily from 30 to 60 minutes. If the furnace is acid lined, and no refining is attempted, the length of a heat is usually from one and one-half to three hours, and the power input is usually held near the maximum value during almost the entire heat. A large number of melting furnaces are operated 24 hours a day, but in the smaller plants, such as foundries, they are usually operated during the daytime only.

Comparing the electric steel furnace load with an ordinary power load, it may be stated that the power-factor of the furnace load will as a rule average at least 85 per cent, which is considerably higher than the overall power-factor of the ordinary motor load. The load due to a single furnace is of course intermittent in character, but where more than one furnace is installed in a plant, the heats can usually be so timed as to give a very good load-factor. It is interesting to note that of the 356 furnaces now installed, 151 are in plants having two or more furnaces each, the number of such plants totalling 55.

If the furnace circuit has a reasonable amount of reactance and the furnace is properly operated, the current surges can be limited to a comparatively low value and made relatively infrequent. Of course, if a melting furnace constitutes a large proportion of the total load on a station, during the first part of

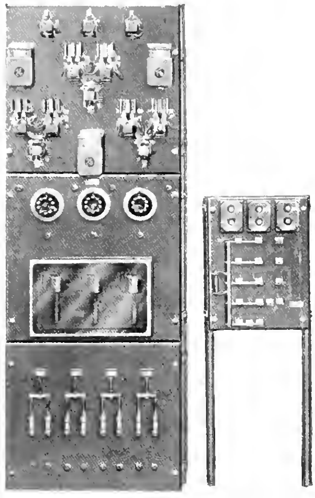


Fig. 6. Electrode Control Panels

the melting period the fluctuations are apt to cause some voltage variation on the system. It is impossible to make any rule as to the maximum allowable ratio between furnace load and total load on a system, but it would seem desirable that the total arc furnace trans-

[illegible]mer rated [illegible] should not exceed 20 per [illegible] capacity.

Induction [illegible] been much used [illegible] United States up to [illegible] evident that these [illegible] used for refining molt[illegible] While the induc[illegible] [illegible]le-phase power, at [illegible] except in very small capa[illegible] frequency lower than 25 [illegible] motor-generator sets to [illegible] frequency power are [illegible] the equipment. These sets are [illegible] with synchronous motor [illegible] load is very steady and free from fluctuat[illegible] and the furnace must be kept [illegible] all times, thus ensuring some load durin[illegible] and Sundays, such an installation makes an ideal load for a central station.

Electric brass melting furnaces vary more in type than do steel furnaces, and each type has load characteristics peculiar to itself. The carbon resistor type of furnace requires single-phase power. Except for this latter feature it is a very good load from the central station viewpoint, as the power input is very steady and free from fluctuations. Where enough of them are installed in a single plant so that they can be distributed on the various phases of a polyphase supply, the fact that they require single-phase power is not so objectionable. The transformer capacity for each furnace is usually not greater than 105 kv-a.

A number of brass furnaces of the single-phase indirect arc type are in use at the present time. The transformer capacity of these furnaces varies from 100 to 300 kv-a. each; and usually sufficient reactance is inserted in the circuit to limit the maximum possible current, with the electrodes together, to not over three times normal. The electrodes of these furnaces can be automatically regulated, with the same type of regulator as is used on steel furnaces. Automatic regulation gives a much more satisfactory load than hand operation. With automatic regulation, the input can be held more steady—after the furnace is heated up—than during the melting period in the ordinary steel furnace. The load characteristics are more nearly like those of the steel furnace during the refining period.

Another type of brass furnace uses the muffled or smothered arc principle of heating. These furnaces are extremely satisfactory as power loads. As at present built they utilize polyphase power in all except a small unit of 50-lb. capacity. The power-factor of the load is usually 95 per cent or better, and it is free from surges such as are incident to the operation of an open arc furnace. The electrodes are automatically regulated, ensuring a very constant and steady load. The transformer capacity of these furnaces ranges from 40 kv-a. on the 50-lb. unit to 400 kv-a. on a 2250-lb. furnace.

Induction type brass melting furnaces are finding a large field in rolling mills and similar plants. These furnaces require single-phase power, at a power-factor of approximately 75 per cent. Ordinarily a number of furnaces are installed in each plant, so that in these cases the single-phase feature is not so objectionable. The great majority of these furnaces are rated 85 kv-a. each, having a maximum output of 600 lb. of brass per hour. These units being of the induction type, at least a portion of a charge of molten metal must at all times be maintained in them. Consequently some power is required during nights and Sundays, regardless of whether the entire plant operates 24 hours a day. The standby power amounts to about 15 per cent of the rated full-load input. Aside from the fact that they require single-phase power, these furnaces constitute a very desirable load for central stations, as the input is steady and free from surges.

From the foregoing it is evident that the electric brass furnace is, as a rule, an even more desirable load than the electric arc steel furnace. The units are of smaller capacity, and a greater number will ordinarily be installed in a single plant than is the case with steel furnaces. This will tend to give a better load-factor. Of the 409 brass furnaces now installed, 278 are in a total of 44 plants, each of which has two or more units.

In conclusion, it may be stated that as a general rule the electric melting furnace constitutes an excellent load for the ordinary central station. This is particularly true of the brass melting furnace, which because of its small demand may be taken on even comparatively small systems.

Electrically Heated Steam Boilers

By Eric A. Lof

Power and Mining Engineering Department, General Electric Company

Eric A. Lof

THE generation of steam by electric current opens up a new industrial field for the utilization of electric power. Its universal use is, however, as yet impossible for economic reasons, but there are many special cases where its application will result not only in a direct economical saving but also in many advantages from an operating standpoint. One particular field where the electric boiler should prove very desirable is in connection with hydro-electric central stations where power can as a rule be obtained at a comparatively low rate and where combustible fuel is generally scarce. Other fields are such industries that rely upon central stations for their power supply and whose manufacturing industries require steam but who desire to do away with the coal fired boiler installation and its many unpleasant detriments. When circumstances are such that excess power is available at certain times, generally at night and on holidays, the economical advantages of an electric boiler plant are apparent; and the possibilities of storing up this surplus power or at least part of it as heat in so-called vapor-accumulators offers many new and interesting problems.

From the technical point of view the electric boiler problem, in general, does not offer any great difficulties and a large number of such boilers are now in successful operation in all parts of the world. Their construction is simple; they require very little floor space and are easy to install on account of the absence of brick settings, stacks, etc. The large heat losses due to the escape of the hot gases through the stacks with ordinary boiler installations are naturally eliminated with the electric boiler, the losses of which comprise only the heat which is radiated to the surrounding atmosphere. By carefully heat insulating the boiler it is possible to reduce these losses to such an extent that the efficiency of electric boilers of average size may be as high as 96 to 98 per cent. The operating force can be reduced to a minimum, and even when the workmen are poorly qualified the automatic control devices will insure that the normal quantity of steam is continuously obtained under even pressure and without the risk of dry-boiling followed by the liability of explosion, which here is quite non-existent. The steam pressure in the boilers can be raised very quickly, in certain cases even within as short a time as ten minutes from the moment the current is switched on, a fact of great importance especially for intermittent working.

In connection with labor saving, it might be interesting to learn what has been accomplished in a large paper mill in Sweden where the electric boiler installation consists of not less than seven 2000-kw. boilers operating at a potential of 10,000 volts and a steam pressure of 10 atmospheres: "In comparison with our old coal boiler plant we now save the expense for about 17 firemen and for all hands, tonnage and rolling stock, otherwise required for the transport, reloading and discharge of coal and ashes, amounting to about 65 tons a day."

In comparing the relative heating values of fuel and electric heat, we have first the fundamental conversion factor of one kilowatt hour equalling 3412 B.t.u. With an electric boiler efficiency of 96 per cent, this figure would then be $3421 \times 0.96 = 3275$ B.t.u. We also find from steam tables that to raise the temperature of one pound of water from, say, 60 deg. F. to 212 deg. F. and a gauge pressure of, say, 100 lb. per square inch there are required 1158 B.t.u. Consequently $\frac{3275}{1158} = 2.82$ pounds of such steam can be generated per kilowatt-hour in the electric boiler.

Assuming a heat value of 14,000 B.t.u. for the fuel which would be burned in the ordinary boiler and that the average efficiency of these is 70 per cent we find that this boiler will produce $\frac{14,000}{1158} \times 0.70 = 8.5$ pounds of steam per pound of coal. Previously we found that in the electric boiler 2.82 pounds of steam would be generated per kilowatt-hour and the ratio of evaporation between the two types of boilers would be $\frac{8.5}{2.82} = 3$.

one k[illegible] heating would therefo[illegible]third of a pound of coal [illegible] $5.00 per ton (2000 lb.) the [illegible] rate 1000 pounds of ste[illegible] $\frac{1000}{[illegible]} \times \frac{5}{2000} = 0.3$ dollars. To [illegible] amount of steam in the electr[illegible] would be required $\frac{1000}{2.82} = 355$ [illegible] order that the power cost for the ele[illegible] heating should not exceed the cost of fuel [illegible] the ordinary boiler, it would be

equivalent to 3412 B.t.u. so that for all practical purposes one boiler horse power is equal to 10 kilowatt-hours of electric energy. A 100-h.p. electric boiler therefore would be rated 1000 kw., a 150-h.p. boiler 1500 kw., etc.

Electric boilers may be classified in two distinct groups: first, such boilers in which the water is heated by means of resistances mounted within the boiler; and, second, such boilers in which the water itself comprises the resistance which is heated when the electric current is passed directly through it from electrodes immersed in it.

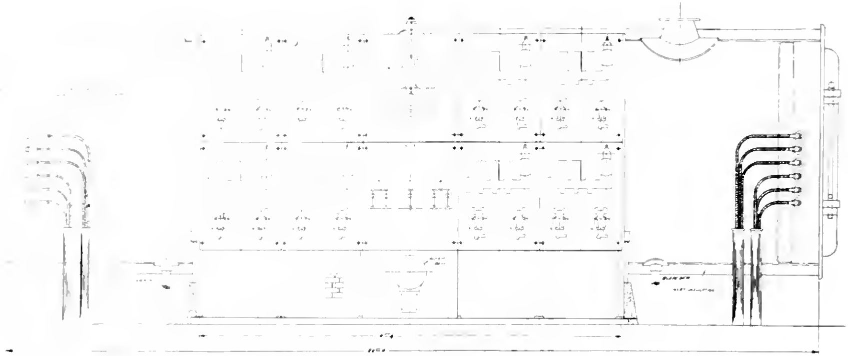


Fig. 1. Diagram of Electrically Heated Steam Boiler of the Metallic Resistor Type, Together with Control Board for Automatically Maintaining the Steam Pressure

Fig. 2. One of the Resistor Heating Units of the Boiler Shown in Fig. 1

necessary to obtain power at not more than $\frac{30}{355} = 0.085$ or less than one-tenth of a cent per kilowatt-hour. This is, of course, only possible in localities where cheap hydro-electric power is available or on the other hand, the cost of fuel may be so high as to make the economical utilization of electric heating look more favorable. The foregoing figures refer, of course, only to the cost of fuel or power and they do not include the operating and maintenance charges which are very much reduced with the electric boiler.

In the rating of steam boilers by horse power, one horse power is equivalent to 33,480 B.t.u. As previously stated, one kilowatt-hour is

Either direct or alternating current may be used with the first named type of boiler having resistance heating elements, as these elements do not come into direct contact with the water. With electrode boilers, however, it is essential to use alternating current as direct current would have a decomposing effect on the water.

There are, of course, a variety of different constructions employed for electric boilers. One of the most satisfactory resistance-unit boilers in this country is the fire-tube boiler. This is admirably adapted to electric heating as the heating units can readily be inserted and supported in the tubes and adequately insulated from them. The heating units in these boilers are a modification of those which have been used for years in large electric resistance furnaces. The unit consists of a heavy ribbon of resistance alloy, supported at frequent intervals by suitable insulators which are clamped to the resistor and are of such size that the unit when assembled will slide freely into a boiler tube.

The units may be connected either in series or multiple and the groups connected Y or delta, and operated on standard voltage circuits such as 110, 220 or 440 volts, single-phase or polyphase, and at any standard frequency. By this grouping of the circuits it is possible to regulate the load of the boiler. For example, a 1200-kw. boiler may be equipped with eight circuits of 150 kw. each, and each of these circuits controlled by a contactor so that the load may be connected or disconnected in steps or operated at only part capacity so that shocks to the system may be avoided. As to the maximum capacity for which boilers of this type may be built, it is obvious that the electrical features are no limitations as it is possible to get more heat into a given boiler electrically than would be possible by fuel firing. Re-equipping old fire tube boilers for electric operation therefore furnishes a ready means for increasing the available boiler capacity.

The boilers can be perfectly controlled by automatic means, using standard boiler room devices applied in a manner adapted to electric operation, and the automatic devices controlling both the steam pressure and water level may be supplemented by positive devices which function in case the automatic devices fail for any cause. The electric boilers are therefore absolutely safe and the insurance rate should be very low.

The sketch shown in Fig. 1 shows an outline of a 1500-kw., 3-phase, 440-volt, electrically-heated steam boiler with control board for automatic pressure control, and Fig. 2 shows one of the heating units.

The second type of boiler which is as yet comparatively new in this country, but which is quite universally used in Europe, is designed on an entirely different principle than is the resistance-unit boiler. Electrodes, usually of iron, are immersed directly in the water and the current is led to them through leads which pass through the boiler cover through steam-tight insulating bushings. The electrodes themselves are often surrounded by cylindrical insulating tubes, which assist the circulation of the water past the electrode. On account of the high resistance of the water and a suitable arrangement of the electrodes, it is possible to utilize currents of very high voltage directly. Several such boilers are in operation using an electrode voltage of 10,000 volts and it is said that twice this voltage may be used successfully for the larger sizes.

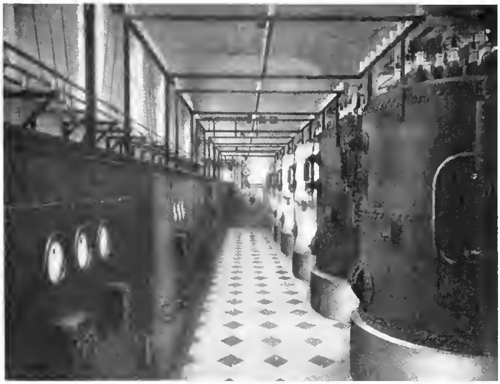


Fig. 3. A Battery of 2000-kw. Steam Boilers in Which the Water Itself Comprises the Heat Generating Resistance

The regulation of the steam production is obtained by providing a number of electrodes and by arranging them in groups which can be cut in or out of the service as the conditions may require. The 2000-kw. boilers shown in Fig. 3 are thus provided with eighteen electrodes in six groups so that the capacity of these boilers can be controlled in steps of one-sixth the capacity by means of switching in or out the respective electrode groups. A closer regulation is, however, possible by changing the composition of the feed water and thus its resistance. A feed-water reservoir is therefore provided with each boiler installation into which the water from the boilers is blown off when, through the evaporation the percentage of dissolved salts exceeds a certain value. As the salt content increases, the resistance of the water falls and the current as well as the load will increase. To bring about a reduction, it is only necessary to blow off some of the salty boiler water into the reservoir and admit sufficient fresh water to bring the resistance to the required value. If on starting up it is found that the water is so pure and its resistance so high as to limit the current to too low a value, it will be necessary to add some of the salty water from the reservoir and thus lower the resistance and increase the load.

In another type of electrode boiler which is exploited in Switzerland, the control of the steam pressure is accomplished by varying the water level in the boiler, which means that the water supply must be continuous. The feed pump is so arranged that it automatically maintains a water level corresponding to the desired load.

Electrode boilers have been built in capacities up to 4000 kw., and it is claimed that there would be no difficulty in building them for twice this capacity.

Alternating-current Motors for High-speed Elevators

By J. J. Matson

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J J Matson

The rapid growth of cities has resulted in two new conditions: (1) an increased power demand; and, (2) a greatly increased land value. The former has caused an increase in the amount of alternating-current power used, on account of less copper being required for alternating-current transmission than is required for direct-current transmission. This increase has been made possible only by the advent of transformers. The latter of the two conditions mentioned has resulted in increasing the heights of all types of buildings, this being necessary in order that income could keep pace with increased land values.

As the height of a building increases, it is only reasonable that a change must be made in elevator characteristics. One of two changes may be effected: (1) the size or number of cars may be increased, maintaining the car speed at a low value; or (2) the car speed may be increased sufficiently to maintain the cars at a relatively small number. The latter is more desirable due to the large amount of additional space thereby made available for renting purposes.

Bearing in mind the large increase in the use of alternating current, as pointed out above, it is evident that it would be very desirable to utilize alternating current throughout any new buildings to be erected. This would insure the building owner the lowest possible power bills inasmuch as he could purchase his power at a very low cost because of taking all of it at the higher transmission voltage and stepping it down for his own distribution. One of the primary applications for electric power in the building will be the elevators, and it is the author's desire to explain methods for utilizing alternating current for this type of service. In doing this, the field will be divided into three classes:

(1) Passenger elevators up to 175 ft. per minute and freight elevators up to about 100 ft. per minute.

(2) Passenger elevators from 175 to 300 ft. per minute and freight elevators from 100 to 200 ft. per minute.

(3) Passenger elevators from 300 to 500 ft. per minute and freight elevators from 200 to 350 ft. per minute.

It has been long recognized that for the first type of service, namely passenger elevators up to 175 ft. per minute and freight elevators up to 100 ft. per minute, the single-speed induction motor is adaptable. Either a slip-ring or squirrel-cage type motor can be used, but it should be pointed out that a squirrel-cage motor is smaller in size and much cheaper than is a slip-ring motor. In building squirrel-cage motors for this service, a high-resistance rotor is employed so as to insure maximum torque at starting as well as a minimum starting current. This type of motor is, therefore, adaptable for throwing directly across the line without exceeding the momentary inrush currents as suggested by the N.E.L.A. rules. A squirrel-cage motor develops approximately 20 per cent more torque than does a slip-ring motor built in the same frame. It is also simpler, has a smaller moment of inertia, and is of more rugged construction than the corresponding slip-ring motor.

For the second class of service, namely, passenger elevators from 175 to 300 ft. per minute and freight elevators from 100 to 200 ft. per minute, a definite low speed for making an accurate landing at floors must be provided. On account of this feature, it has been deemed advisable until just recently to supply direct-current adjustable-speed motors and to use a motor-generator set or synchronous converter for changing from alternating-current to direct-current power. It is now, however, a proved fact that two-speed alternating-current motors are very satisfactorily adapted to this type of service.

In order to secure as rugged and cheap a motor as possible, the squirrel-cage type of motor has been thoroughly investigated and one developed which has a speed ratio of 2:1. This motor has a single winding in the primary and a single high-resistance rotor winding. The motor speed is changed by means of an external pole-changing switch which connects the motor at either speed directly across the line. The simplest control as well as the simplest and most rugged type of motor is thus insured. The low-speed connection is used only during starting and stopping. On starting the elevator, the motor is first connected to the line at low speed. After accelerating to approximately full speed for this connection, the number of poles is changed by the pole-changing switch, the motor then accelerating to its full-rated speed. On stopping, the motor connections are changed in the reverse order. A block of resistance is inserted in series with the primary at the instant of changing connections, the effect being to smooth out the deceleration. After a given time interval, this resistance is short circuited and the motor is directly across the line. This gives a slow down to approximately one-half full-load speed and, when used with the car speeds mentioned, an accurate landing can be made.

In order to insure satisfactory accelerating characteristics, the low-speed connection is designed to give a starting torque of 250 per cent full-load running torque and the high-speed connection has a starting torque of 200 per cent full-load running torque. In starting two current peaks are experienced, the first when connecting at low speed to the line and the second when changing from the low to the high-speed connection. The latter is the more severe and gives a momentary current peak of from 260 to 270 per cent of full-load current. A well damped ammeter would read 75 per cent of this or would indicate a current at throw-over of from 195 to 203 per cent full-load current. Thus the starting currents on this type of motor are well within the limits as suggested by the N.E.L.A. covering the throwing of squirrel-cage motors on the line.

TABLE I

Motor Characteristics	Single-speed, Squirrel-cage Motor	Slip-ring Motor	2:1 Two-speed Squirrel-cage Motor
Starting torque lb-ft. at 1-ft. radius	410	440	520
Full-load torque (40 per cent starting torque)	164	176	208
Synchronous speed r.p.m.	900	900	900 450
Full-load speed r.p.m.	712	855	722
Average load speed r.p.m.	872	893	873
Starting current amperes	220	215	245
$\frac{\text{Lb-ft. starting torque}}{\text{starting current}}$ (see Case A)	1.86	2.04	2.12
$\frac{\text{Lb-ft. starting torque}}{\text{starting current}} \times$ full-load r.p.m. (see Case B)	1330	1750	1525
$\frac{\text{Lb-ft. starting torque}}{\text{starting current}} \times$ av. load r.p.m. (see Case C)	1630	1828	1850
Rotor moment of inertia, Lb-ft.^{2}	35	65	52
Kilowatt-seconds consumed in friction brake when stopping from synchronous speed	6.5	11.75	2.5

Table I shows the comparative characteristics of the single-speed squirrel-cage motor, the single-winding 2:1 squirrel-cage motor and a single-speed slip-ring motor. The relative merits of these motors will be considered in three ways:

Case *A*, assuming the same gear ratio regardless of motor speed. This comparison is shown by the ratio

$$\frac{\text{lb-ft. starting torque}}{\text{starting current}}$$

[illegible] motor to be geared [illegible] load. This com- [illegible] ratio [illegible] at full load [illegible]

[illegible] motor to be geared [illegible] car-miles per day. This com- [illegible] ratio [illegible] at average load [illegible]

[illegible] average load is assumed to be [illegible] the counterweights, giv- [illegible] assumed friction load of 15 per cent on [illegible] motor. It has been assumed that the [illegible] consumed by each type of motor [illegible] starting and stopping, and no allowance [illegible] been made for the more accurate landing [illegible] results with the 2:1 motor. If allowance were made for accuracy of landing at floors, the 2:1 motor would show up better than the comparative ratios of car mileage now indicate.

In all comparisons, the starting torque has been assumed to be 250 per cent full-load running torque. The slip-ring motor discussed has a low density and would be the type recommended when a slip-ring motor is desired for a high-grade passenger elevator. In these comparisons the larger the various ratios are the better the motor for this type of service.

This comparison shows the 2:1 two-speed squirrel-cage motor to be best when all three motors are geared the same or when they are all geared to give the same car-miles per day. The slip-ring motor shows up best when all are geared to give the same car speed at full load. If this latter method of gearing were used, however, both types of squirrel-cage motors would give a higher value of car-miles than would the slip-ring motor, due to the greater variation in motor speed obtainable with the squirrel-cage motors than with the slip-ring motor between full load and average load conditions. This comparison again neglects the accuracy of landing. If this were considered, the single-speed motors, of both the slip-ring and squirrel-cage type, would show a reduction in car-miles per day on account of the time lost in jogging at landings, while the 2:1 squirrel-cage motor would remain unchanged as its low-speed connection gives a definite low speed from which an accurate landing can be made. The 2:1 motor should make from 15 to 30 per cent more car-miles per day than will the slip-ring motor, assuming both elevators are discharging and receiving passengers the same amount of time during the day.

The single-speed squirrel-cage motor shows up poorest in all cases except when flywheel effects are considered, which shows this type of motor to be best. Also the squirrel-cage single-speed motor requires less friction braking than does the slip-ring motor; but on account of the slowing down for landings being electrically accomplished with the 2:1 squirrel-cage motor it requires even less friction braking than does the squirrel-cage single-speed motor.

The foregoing discussion shows the great importance attached to selecting the proper method of gearing. This feature should always be carefully considered and the fact be kept in mind, that passenger elevators carry maximum load only about one hour per day and freight elevators carry maximum load very infrequently. It therefore appears that the proper way to gear is for rated car speed at average loads, as this not only gives the best speed regulation but also the best motor application.

Many writers have pointed out the power saved by using an adjustable-speed instead of a single-speed direct-current motor on elevator service. For like reasons, the 2:1 squirrel-cage motor takes less power than a single-speed motor. This saving results from two causes:

(1) Due to the low-speed connection requiring only one-half the power of the high-speed connection. As operation up to half speed and all jogging is done on the low-speed connection, a saving in power results. This is shown in Fig. 1 by the areas marked "A."

(2) With a 2:1 motor some power is returned to the line by the low-speed connection during slow down to low speed. This is shown by area "B" in Fig. 1.

As any elevator makes from 100 to 300 stops per car-mile the advantage of these savings in power is apparent.

For the third class of service, namely, passenger elevators from 300 to 500 ft. per minute and freight elevators from 200 to 300 ft. per minute, a motor having a speed ratio of 3:1 is required to insure a sufficiently low speed for accurate stopping at floors, as well as to permit friction brakes of feasible size to be used.

Three general types of motors may be considered for this service:

(1) A two-speed slip-ring motor having a double set of primary and a double set of secondary windings.

(2) A squirrel-cage motor having two primary and one secondary winding.

(3) A double motor set consisting of a slip-ring and squirrel-cage motor mounted on the same shaft and within the same supporting frame. This design is in reality two motors in the same frame since the squirrel-cage and slip-ring motors each have their own magnetic field and do not have any electrical or magnetic connections to each other.

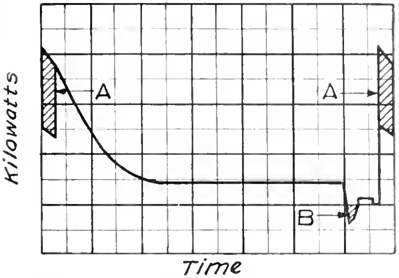

Fig. 1. Elevator Duty Cycle Curve. Shaded Area *A* represents power saved, and Area *B* power returned to line, by a 2:1 squirrel-cage motor

The 3:1 slip-ring motor just discussed has the following disadvantages:

(1) A motor of large diameter is required on account of the double primary and secondary windings used. This increases the moment of inertia of the rotor which causes increased power consumption and motor heating during acceleration.

(2) Cooling is hindered by each winding having to radiate heat through the other.

(3) In case of an inner coil burning out, both windings must be removed in order to repair the motor.

(4) When either winding is connected to the line some of the iron is not in use. This results in a machine having a relatively poor power-factor and efficiency.

The squirrel-cage motor having double primary windings has the same four disadvantages as the 3:1 slip-ring motor. It should, however, be pointed out that the heating of the squirrel-cage motor is even worse than discussed under objection (2), on account of the losses at starting being all inside the motor while with the slip-ring motor considerable of the losses are dissipated by the resistor. On account of this heating condition during starting, the squirrel-cage motor is not satisfactory for very high speed passenger elevators where a great many starts are made per day. The squirrel-cage 3:1 motor may be very wisely used on freight elevators where a large speed ratio is desired but relatively few starts are made.

The double motor set described has been developed, keeping all the foregoing objections in mind with the following results:

(1) This type of motor is easily repaired inasmuch as each winding is at all times accessible.

(2) The heating of the low-speed motor is greatly lessened, due to its being ventilated by the windage set up by the high-speed winding when in operation.

(3) Neither winding must radiate heat through the other, thus the cooling effect is greatly increased.

(4) Instead of making a large diameter unit, the machine is kept narrow and long as one winding is not on top of the other. This results in a greatly decreased value of the moment of inertia; also, since each winding has its own iron, the iron is more efficiently utilized giving a motor having much better electrical characteristics than results when superimposed windings are employed.

The double motor set may be started by either throwing both the squirrel-cage and slip-ring motor, with resistance in circuit, on the line or by throwing the squirrel-cage motor only on the line. In case a load of twice the elevator capacity is to be handled, this type of motor could be used by connecting both motor windings to the line, the slip-ring motor having a block of resistance in circuit. A hoisting speed of approximately one-third full-load speed would result. A switch could be mounted on the switchboard to permit these motors to operate in parallel. This increased capacity which is often desired is sometimes taken care of by the use of a changed gear ratio. This method is, however, expensive and also is rather difficult as either gears or pinions must be changed.

In conclusion, it might be stated that the increase in elevator speeds will make two-speed elevator motors mandatory, and from the advancement already made it seems certain that we are just entering upon another large field of induction motor application.

Electrochemical Industries

By John A. Seede

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John A Seede

In considering those industries in which electric power is used for various purposes other than transmission and distribution of energy for mechanical purposes, we may make a narrow classification, including only those where electrolysis, either at low or high temperatures, enters largely into the process, or we may take a broader view and include the processes that are partly or wholly electrothermic.

By adopting the latter arrangement, we immediately pass from applications where direct current is solely used, and include another field where it is seldom used and in which changes are caused by the electrical heating of the charge to the temperature where the chemical and physical changes take place. In this second division alternating current is used almost exclusively, chiefly on account of its ease of control and distribution when dealing with heavy currents.

One of the important branches of electrochemistry is electrometallurgy, and in the latter are certain electrothermic applications of steadily growing importance, such as the smelting, melting and refining of various metals and alloys. The first electric furnaces for melting and refining steel were installed about 1904 and for a long time were regarded with contempt, and only as a laboratory device, by nearly all steel makers, crucible and open hearth alike. Slowly the electric furnaces made their way, so that today we have three electrode furnaces normally rated at 40 tons holding capacity, but capable of pouring about 65 tons, and double this capacity with six electrodes is already talked of for the near future. For all practical purposes electric furnace steel can be made as good as crucible steel, and for ordinary cast steel there is no comparison between electric furnace steel properly made and most of the ordinary commercial cast steel. A little later the brass melting furnace was developed and the percentage expansion of these furnaces, in all types, has far outstripped that of the steel furnaces. Electric furnaces for cast and malleable iron have been slow in application, but developments are under way and may soon be expected to become a factor in this line.

With this idea in mind, we recognize another classification where the entire industry is based on the process, or the opposite condition where the process is a subordinate part and simply supplies a purified product as raw or finished material. In both cases the cost of power is an important factor; in the former, where a power plant has not been built as an integral part of the industry, power is purchased in large blocks at a flat rate per horse-power year, and in the latter it is generally purchased by the kilowatt-hour from the central station.

Many examples of the first case immediately occur to the reader, such as the manufacture of nitrates and nitrites, caustic soda, aluminum, zinc, ferro-alloys, calcium carbide and cyanamid, etc., while the production by

TABLE I

ELECTROCHEMICAL PRODUCTS

Electrothermic Products		Electrolytic Products	
Main	Subordinate	Main	Subordinate
Alundum Calcium Carbide Calcium Cyanamid Carbon Bisulphide Ferro-alloys Graphite Iron Nitric Acid Phosphorous	Barium Oxide Melting and refining of various metals and alloys	Aluminum Caustic Soda Iron Lead Magnesium	Chlorine Hydrogen Oxygen Refining of Metals

electrolysis of oxygen and hydrogen for cutting and other uses, and of chlorine and allied products in the paper industry, etc., are examples of the second case. It is evident that the secondary applications are relatively insignificant from the standpoint of total energy consumption, but these products have become indispensable and the manufacture of the apparatus for their production is the basis of industries of steadily growing importance.

Instances will be found where an entire plant will be engaged in the manufacture of a single product in a given location, while at a short distance the same product will be manufactured on a much smaller scale as a necessary adjunct to other major processes. The explanation is that in the second case, while the cost will be somewhat higher, the control of all factors entering into the manufacture of the principal product will more than compensate for the slight difference in cost.

Fig. 1 Nitrogen Fixation Development at Rjukan, Norway

Table I shows one method of dividing the various applications, although it is obvious that other arrangements might be used, such as a classification according to power supply—direct or alternating current, continuous or intermittent cycle, single or polyphase current, high or low power and load factors, etc.

This classification shows products that can be made by non-electric processes, and omits unusual or subsidiary products that are of importance but need not be included here for various reasons, the main idea being to show the range of electrochemistry as it affects our industrial life.

In Table II some of the more important products are listed, with approximate energy consumption required for their production from which, assuming power to be furnished at \$20 per horse power year, we can derive the percentage cost of the power to the market price of the product. Obviously power at this low figure can be obtained in only a few localities, but the same figure is used throughout in order to obtain a basis of comparison.

Table III is given covering the melting and refining of a few metals and alloys because of the increasing use of the electric furnace for this purpose and public interest therein. The cost of power is figured at 2 cts. per kw-hr., as being representative of average practice and therefore the percentages are more in accord with actual practice.

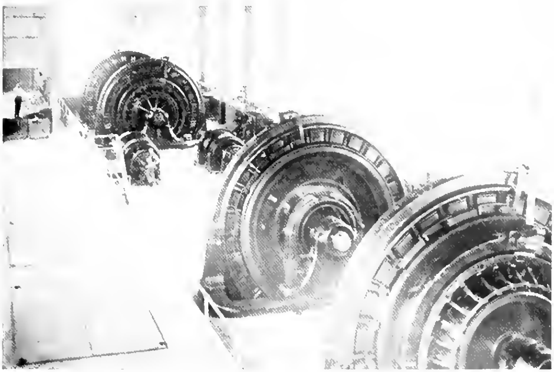

Fig. 2. In this Substation are four General Electric Synchronous Converters, each supplying 13,000 amperes at 525 volts for the electrolytic production of aluminum. A fifth unit has later been added, making the total capacity of this station 65,000 amperes

Alum[illegible]

[illegible] only a short [illegible] is finding [illegible] our lives in [illegible] in household [illegible] electrically operated [illegible] duced by the electrol- [illegible] dissolved in molten [illegible] ing been discovered [illegible] time by Hall in this [illegible] in Europe [illegible] great amount of power

bauxite, is mixed with coke, which reduces the oxides of iron, silicon and titanium, and these are eliminated.

Barium Oxide

In the manufacture of sugar, barium oxide is becoming of increasing importance and is made from a mixture of barium carbonate and coke in the electric furnace, using direct-current energy. This is one of the exceptional cases where direct-current energy is used in the electric furnace and it is claimed that part of the effect is due to electrolysis.

TABLE II

ELECTROCHEMICAL PRODUCTION OF VARIOUS MATERIALS

Material	Process	Kw-hr. Per Ton	Present Market Price of Product	Cost of Power Per Ton	Per Cent Cost of Power to Market Price
Aluminum	Electrolytic	30,000	$570	$90.00	15.8
Alundum	Electrothermic	2,000	60	6.00	10.
Barium Oxide	Electrothermic	1,200	*	3.60	*
Cadmium	Electrolytic	2,500	2,200	7.50	3.4
Calcium Carbide	Electrothermic	4,000	80	12.00	15.
Calcium Cyanamid	Electrothermic	3,750	300	11.25	3.75
Carbon Bisulphide	Electrothermic	850	160	2.55	1.6
Carborundum	Electrothermic	8,500	*	25.50	*
Caustic Soda 2000 lb. Chlorine 1760 lb.	Electrolytic	3,000	72 220	90.00	30.8
Copper	Electrolytic Refining	300	240	.90	.38
Copper	Electrolytic	2,600	240	7.80	3.25
Ferro-Chromium (60%)	Electrothermic	8,000	180	24.00	13.3
" Manganese (76%)	Electrothermic	5,000	90	15.00	16.6
" Molybdenum (60%)	Electrothermic	8,400	3,000	25.20	.84
" Silicon (50%)	Electrothermic	5,000	80	18.00	22.5
" Silicon (75%)	Electrothermic	10,000	135	30.00	22.2
" Tungsten (70%)	Electrothermic	7,600	700	22.80	3.25
" Uranium (40%)	Electrothermic	8,000	4,800	24.00	.5
" Vanadium (35%)	Electrothermic	6,800	3,500	20.40	.58
Graphite	Electrothermic	7,800	200	23.40	11.70
Iron	Electrothermic	2,500	*	7.50	*
Iron	Electrolytic	4,000	*	12.00	*
Lead	Electrolytic Refining	145	70	4.35	6.2
Magnesium	Electrolytic	27,000	2,500	81.00	3.24
Nitric Acid	Electrothermic	17,500	*	52.50	*
Phosphorous	Electrothermic	12,000	720	36.00	5.
Potassium Chlorate	Electrolytic	1,350	150	4.05	2.7
Sodium	Electrolytic	20,000	400	60.00	15.
Sodium Chlorate	Electrolytic	7,000	170	21.00	12.3
Tin	Electrolytic Refining	175	570	.525	.09
Zinc	Electrolytic	4,000	120	12.00	10.

* Figures not available

required, it is necessary that the industry control the power supply, and in practically all cases the power developments have been made by the manufacturer.

Alundum

This material is made by fusing alumina (aluminum oxide) in the electric furnace and the final product is used for various purposes, principally abrasives. Impure alumina, called

Cadmium

This unusual metal is obtained by electrolysis of the condensation products from lead and copper furnaces.

Calcium Carbide and Cyanamid

As a source of acetylene and as a starting point for the manufacture of calcium cyanamid and many other materials, calcium carbide is an important substance.

It is usually made from a mixture of coke and lime in an open top polyphase electric furnace of very large capacity. In Fig. 1 is reproduced a 24-hour chart of the power input to such a furnace, the automatic regulator maintaining the power input within one

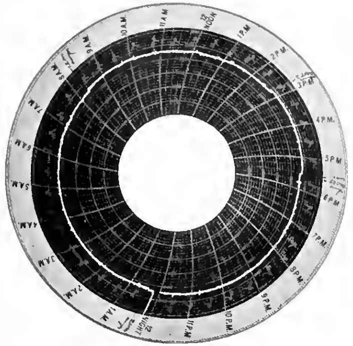

Fig. 3. Chart Indicating the Desirable Load of Large Electric Furnaces. It is a 24-hour load chart from a large calcium carbide furnace, the current being controlled within one per cent by a General Electric automatic electrode regulator

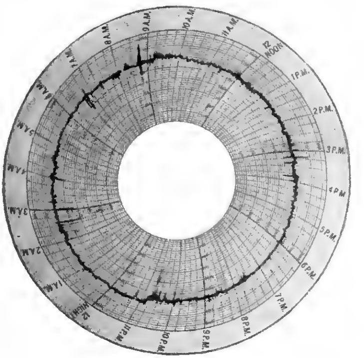

Fig. 4. A 24-hour Chart from a 1500-kw. Ferro-alloy Furnace, Controlled by General Electric Automatic Electrode Regulator. On account of the nature of the alloy, the load fluctuated somewhat but the load-factor was 96.2 per cent

per cent. With such an ideal load it is not surprising that the load factor approximates very closely 100 per cent. The well known process of crushing the calcium carbide and treating with nitrogen to form calcium cyanamid, having a nitrogen content of approximately 20 per cent, is too well known to require further discussion here or comment on its importance as a source of artificial fertilizer.

Carbon Bisulphide

This material which finds many important applications in the arts is made by the direct combination of sulphur and coke in the electric furnace, the process having been developed principally by E. R. Taylor at Penn Yan, N. Y. It has been made by other processes not using the electric furnace, but for safety to the operators, quality of product and continuity of production the electric furnace process is far superior to the old methods.

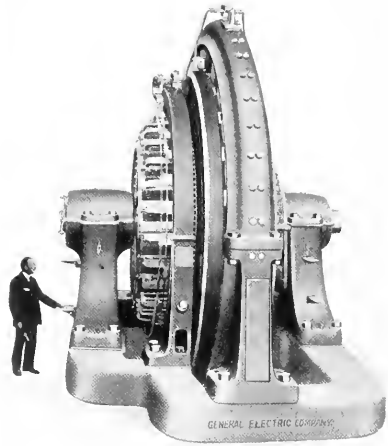

Fig. 5. Enormous Size of a Large Rotary Converter for Electrolytic Work, the output being 13,000 amperes at 525 volts

Carborundum

Carborundum, which differs radically from that class of artificial abrasives made by melting and purifying bauxite, is made by the reduction of silicon oxide, the silicon thus liberated combining with carbon to form silicon carbide.

In addition to its use as an abrasive, it finds many other important uses, such as high grade refractory material in furnace construction.

Caustic Soda

The manufacture of caustic soda and potash, sodium chlorate, potassium perchlorate, and various other products and by-products such as chlorine, is the basis of large industries. These substances are principally obtained by [illegible] electro[illegible] [illegible]tions of sodium and potassium [illegible]. Considerable work has been [illegible] the cells to overcome [illegible] encountered in this work, and [illegible] require low power rate[illegible] older processes not use[illegible]

Copper

The electrolytic refining of copper is the [illegible] industry using large amounts of power. As the anodes contain only small impurities, the amount of power consumed per ton is low, but where copper is deposited from solutions direct from the ore, using insoluble anodes, the power consumption increases considerably, or from 300 kw-hr. to 2600 kw-hr.

Ferro-alloys

Because of their importance in the steel and iron industries, and because of the relationship of these industries to our national prosperity, it is not exaggeration to say that the ferro-alloys are the most useful products of the electric furnace. Of these various alloys probably the most important are the various grades of ferro-silicon without which it would be impossible to secure the excellent grades of sheet steel that are now used in the manufacture of motors, generators and transformers.

A low grade ferro-silicon is made in the blast furnace, but the impurities are too numerous and the silicon content too low to permit its use in the more important steels.

Electric furnace ferro-manganese, although finding more competition in the blast furnace product than any other ferro-alloy, is of considerably greater purity and therefore better adapted to the manufacture of manganese and other alloy steels.

Of the other ferro-alloys listed above, all are used in the manufacture of high grade alloy steels and several have special uses, such as ferro-chromium in the manufacture of stainless and corrosion resisting steels, ferro-vanadium in spring manufacture, and both alloys, together with ferro-tungsten, ferro-molybdenum and ferro-uranium in the production of high speed steels.

Fig. 6. An Up-to-date Electric Furnace Installation for Producing High-grade Tool Steels. The present equipment consists of four 6-ton furnaces, each taking 1500 kw.

Artificial Graphite

The manufacture of artificial graphite from anthracite coal and other materials is one of the major industries at Niagara Falls and is directly responsible for our being able to obtain graphite electrodes. It is also valuable as a source of very pure graphite for lubrication purposes, the artificial material containing on the average approximately 0.5 per cent impurities as compared to natural graphite which seldom contains less than 5 per cent. This material is an outgrowth of the carbo-

TABLE III

ELECTROTHERMIC MELTING AND REFINING OF METALS

Market Price Per Ton

Material	Kw-hr. Per Ton	Raw Materials	Product	Power Cost at Two Cents	Per Cent Cost of Product
Aluminum	500	$570	$1200.00	$10.00	.8
Brass	300	200	600.00	6.00	1.
Bronze	330	300	800.00	6.60	.82
Cast Iron	450	25	90.00	9.00	10.
Cast Steel	600	25	150.00	12.00	8.
High Speed Steel	750	400	1500.00	15.00	1.

rundum industry, graphite being found in the center of the furnace as the silicon was vaporized by heating the silicon carbide above 2700 deg. C.

Iron

The electrothermic smelting of iron ores in Scandinavia is well known to all interested in electrochemistry and has achieved considerable success under certain conditions. On account of the purity of the product, it is better suited for the manufacture of high grade steel than the ordinary blast furnace product and will undoubtedly have considerable usefulness in some industries.

The electrolytic refining and deposition of iron has not been worked out commercially except at Grenoble, France, where a plant is in operation. If this process can be worked out to use iron ore as a starting point, along the lines developed in the electrolytic production of copper and zinc, we will have a solution of the problem of producing iron in those localities where iron ore and cheap water power are available, but where coke and charcoal are not, such as Canada, Scandinavia, India and South America.

Magnesium

This element, prepared by the electrolysis of fused salts, is the lightest metal used in commercial quantities and will probably be one of the most important metals of the future. In combination with aluminum, several alloys, magnalium, etc., combining great strength with extreme light weight, are available and are extensively used for automotive and aviation purposes.

Nitric Acid

This is another Scandinavian development which requires large amounts of cheap water power, but in view of the recent developments in the direct synthesis of nitrogen and hydrogen, it is doubtful if the present processes can continue to compete.

Phosphorous

The production of phosphorous in the electric furnace is a comparatively limited development and comes under the class of operations where the material is produced in vapor form and condensed, similar to electrothermic production of zinc.

Zinc

After a long period of research work, the electrolytic production of zinc from zinc sulphate has been worked out successfully. From the standpoint of cost alone, it is probable that the electrolytic process can successfully compete with the standard retort process, and when quality is taken into consideration, especially when the ores contain silver and gold, the electrolytic process not only can compete but in practically all cases controls the field.

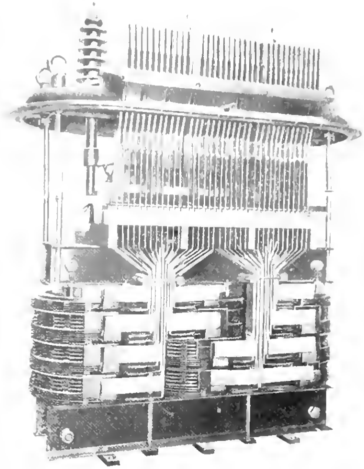

Fig. 7. Large Electric Furnace Transformers are the product of long experience and high skill, and the making use of the best materials available. This transformer takes power at 44,000 volts and delivers to each of three electrodes 26,600 amperes at 85 volts

General

At the present time the chief industries of interest to the central station, electrochemically speaking, are those which use electric power to melt and refine various metals and alloys, specially brass, bronze, iron, and steel, and certain electrolytic developments such as electrolytic deposition of various metals and electrolysis of water. However, as the combinations of power companies continue to increase, they will better appreciate the problems of the electrochemist and be able to handle his power requirements. The electrochemical industries are not over 30 years old and have had to hunt for sources of power as for any other raw material forming a necessary part of the process.

In future developments, may we not look for closer co-operation between the electrochemist and the power engineer, knowing that the former can supply the most desirable load the latter can reasonably ask for, if power station schedules are arranged to conform to the requirements of the chemist?

Electric Drive for Machine Shops

By B. S. Pero

Power and Mining Engineering Department, General Electric Company

B S Pero

PRACTICALLY every manufacturer is interested in machine shops, and consequently in machine tool drive. Although some need the machine shop only for repair and experimental work, many more use it for regular production work and for this purpose the efficient drive of the machine tools is of great importance. The application of individual motor drive has many advantages, and is now generally recognized as a necessity for maximum production.

Belts and line shafting are eliminated, better natural lighting and use of cranes are obtained, a saving in building construction is made possible, and heretofore unused space becomes available because of the unrestricted location of the motor-driven tool. Fig. 2 shows the clean cut and very desirable layout possible with individual drive. This photograph was taken in an up-to-date plant in which machinery is the product. Generally, power is saved by individual motor drive, although the connected load in motors is usually greater than the required rating of an engine necessary to drive the shop. The major saving is due to the increase in production made possible by the ability of the electric motor to maintain the machine speed under heavy load conditions and by the convenience with which the portable motor-driven tool can be brought to heavy or cumbersome work.

To illustrate the losses caused by belts slipping, a belted planer was selected. The cut was increased until 21-h.p. load was shown, at which the planer stopped and the belt slipped. The construction and size of the planer permitted of a 25-h.p. direct-coupled motor being used, and this motor took care of the test cut very well.

In the average machine shop where individual drive is used, the total load is remarkably constant, because a great many motors of comparatively small rating are used and when one machine is shut down there is likely to be one starting.

The load-factor of an entire shop will usually average about 40 per cent. Very few tools demand full output of the driving motor continuously throughout the work period, and the time factor, or percentage of time that the machine is running, averages about 50 per cent. "Waiting for cranes" is one of the reasons for idle periods which mean less production, as well as reduced time factor, and can be eliminated only by improved work handling devices.

For constant-speed work, the squirrel-cage induction motor is very desirable. It is free from sliding contacts, is of simple construction, and very reliable. Assuming central station power is being used, the induction motor usually requires only a transformer for reducing the service voltage. In all machine shops there are machine tools that require adjustable-speed motors, and for that reason a certain amount of direct current is necessary. The average of a number of plants shows that about 50 per cent of each type of motor is required.

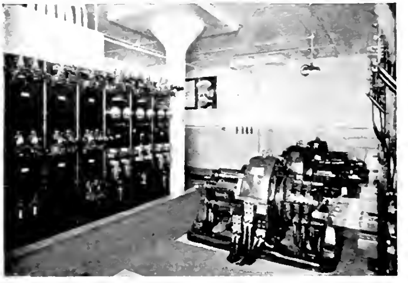

Fig. 1. Three 300-kw., 1200-r.p.m., 250-volt Synchronous Converters and Direct-current Switchboard, Bullard Engineering Works, Bridgeport, Conn.

Synchronous converters or motor-generator sets are used for transformation to direct current. The machines and switchboard shown in Fig. 1 supply the direct-current power used in the shop illustrated in Fig 2.

The crane load in a great many plants is quite an item, and with this as an incentive a vast amount of experimental work has been carried on with the result that very satisfactory alternating-current crane equipments have been developed.

From the foregoing, it will be noted that the most desirable arrangement is obtained when both alternating-current and direct-current motors are applied. This scheme is used in the shop shown in Fig. 2, the direct-current connected load being approximately 450 h.p. and the alternating-current load amounting to about 400 h.p. The purchased power is alternating-current and is furnished by a central station.

All machine tools that are driven at constant speed should have alternating-current motors applied, and those requiring adjustable speed should be driven by direct-current motors. The exception for constant speed is where very high torque is required which would probably call for a direct-current compound-wound machine. Care should be taken in the application of alternating-current variable-speed motors, which are often erroneously applied where adjustable speed is required. The variable-speed induction motor should only be applied where the torque required is constant. This condition will not be found in a machine tool that requires an adjustable-speed motor.

In general, all machine tools used to remove metal by means of cutting tools or abrasives produce constant loads and can be driven by shunt-wound direct-current or constant-speed alternating-current motors. The class of tools used to form or shear metal generally produce high intermittent peak loads, and should be driven by compound-wound direct-current or high-torque alternating-current motors.

Fig. 2 Machine Shop, Bullard Engineering Works, Bridgeport, Conn.

Besides cranes, for transporting material in the shop, the electric tractor and truck have come into extensive use. It is possible to charge the batteries of these vehicles during the night, thereby producing a 24-hour load. Many large plants use battery locomotives for yard hauling, thereby decreasing the day demands considerably below what they would be if these locomotives were drawing on the power station direct. Electric tractors can get into otherwise inaccessible places, and do much toward decreasing the time usually required for transporting the work to and from the different machines. These work transporting devices should be used to increase the 50 per cent time factor referred to in the first part of this article.

Electric Drive for Small Automatic Self-dumping Skip Hoists

By R. H. McLain and C. B. Connely

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R. H McLain

C. B. Connely

SMALL automatic self-dumping skip hoists are generally used for ash removal and coal hoisting in power plants and railway locomotive coal stations, and in handling free-flowing bulk material of various kinds. It is believed that their field of usefulness could be further extended if their limitations were studied and means of improving their characteristics were pointed out from the standpoint of power application.

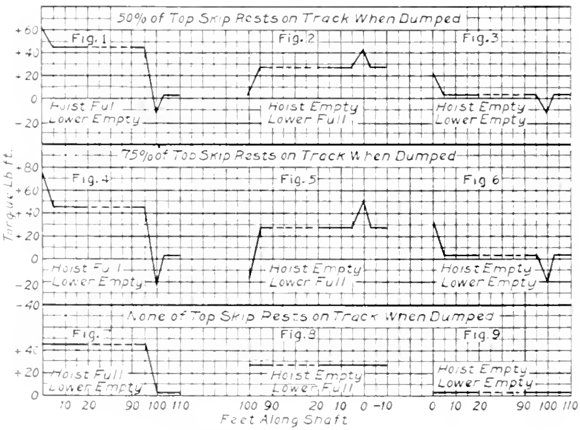
There are three general classes of self-dumping skip hoists. All are equipped with a special skip bucket which, when drawn into cams at the top, either tilts over and discharges from its top or opens and discharges at the side and bottom, and then rights itself when lowered back into the skip shaft.

Class 1 is the unbalanced skip hoist, and its requirements are:

(a) Power for hoisting a full skip.
(b) Power for hoisting an empty skip.
(c) Brake for lowering an empty skip.
(d) Brake for lowering a full skip.

Class 2 is the counter-weighted skip hoist. The counter-weight may be of any value, but for the purposes of this article it will be considered to be equal to 100 per cent of the skip plus 60 per cent of the material in the skip. Its power requirements are:

(a) Power for hoisting a full bucket.
(b) Brake for hoisting an empty bucket.
(c) Power for lowering an empty bucket.
(d) Brake for lowering a full bucket.



Figs. 1 to 9. Typical Rope Pulls of Balanced Skip Hoists Expressed in Lb-ft. Torque at Motor Shaft

Class 3 is the balanced skip hoist. It consists of two dumping skips and skip-ways, one of which is lowering while the other is hoisting. The power requirements are:

(a) Power for hoisting a full skip and lowering an empty skip.
(b) Power for hoisting a full skip and lowering a full skip.
(c) Power for hoisting an empty skip and lowering an empty skip.
(d) Brake for hoisting an empty skip and lowering a full skip.

The rope pulls change while material is being dumped and while some of the weight of the top skip may be resting on the dumping cams, and Figs. 1 to 9 inclusive are plotted to show the motor torque required for Class 3 hoists under conditions (a), (c) and (d), it being assumed that speed is constant. These curves are plotted with motor torque as ordinates and feet along the skip-way as abcissae.

The following standard assumptions are made:

Drums are cylindrical.
Weight of skip 100 per cent.
Weight of material in skip 100 per cent.
Weight of counter-weight (when used) 160 per cent.
Motor speed 900 r.p.m.
Height of hoist 100 feet.
Weight of the rope is neglected.
Normal amount of rope drawn in when skip is being pulled into the dumping cams is 5 ft.

The skip or counter-weight when at the bottom is suspended entirely on the rope; also the counter-weight when at the top is suspended entirely on the rope. A variation in this arrangement can easily be made by

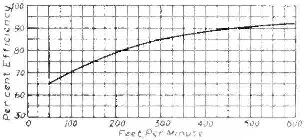


Fig. 10. Theoretical Skip Hoisting Engine Efficiency from Motor Shaft to Rope

allowing some of the weight of the skip at the bottom to rest either on a weigh-beam or a cam-shaped track. Such an arrangement can be made to materially improve the duty cycle, especially as regards accuracy of stopping and amount of starting torque. (Figs. 7, 8, and 9, while not plotted to cover this condition accurately, illustrate the nature of the advantage obtained.)

When the skip is in the normal fully dumped position at the top, either 100 per cent, 50 per cent or 25 per cent of the weight

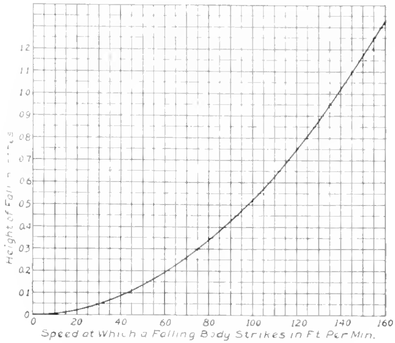


Fig. 11 Speed at Which a Falling Body Strikes Versus Height of Fall in Inches

of the skip may be suspended from the rope, the remainder resting on the dumping cams. The amount of weight which hangs on the rope depends upon the type of bucket and cams. Distinction will be made between the duty cycles under each of the three conditions. When the skip is drawn 3 feet of rope travel above the normal position of dumping, 100 per cent of the weight of the skip is suspended from the rope.

The losses in sheaves and the shaft friction for a skip are taken as 3 per cent of the rope pull produced by that skip in a vertical shaft.

The mechanical efficiency of the hoisting machine between motor pinion and rope is taken as 85 per cent.

An additional set of curves, Figs. 12 and 13, are plotted to show how great is the variation in the point of stopping both at the top and at the bottom when certain of these conditions vary. In this set of curves the variation of the stopping point in feet is plotted as ordinates against the skip speed in feet per minute as abscissae. These variations are caused by the following variations in hoist conditions, which are now used to supersede certain assumptions made above:

The hoist machine efficiency will now be taken as 65 per cent for 50 ft. per minute speed, and will vary up to 85 per cent for

300 f[illegible] per m[illegible] [illegible] up speed, as shown on Fig. 10.

Reference [illegible] Tables I and II will show that [illegible] ranges from 95 per cent of [illegible] for hoisting to 121 per cent for low[illegible] and 95 per cent for hoisting to 113

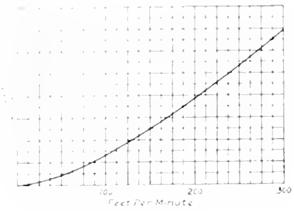


Fig. 12. Variation in Stopping in Feet Versus Normal Hoisting Speed Under Following Conditions

Hoisting an Empty Bucket and *Lowering a Loaded Bucket*
Balanced Skip
50 Per Cent Weight of Dumped Skip on Rails
150 Per Cent Nominal Brake Setting
Limit Switch Setting for Normal Stop When Hoisting Loaded Bucket and Lowering Empty One

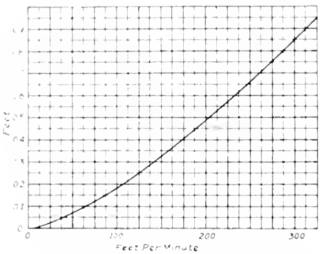


Fig. 13. Variation in Stopping in Feet Versus Normal Hoisting Speed Under Following Conditions

Hoisting an Empty Bucket and *Lowering an Empty Bucket*
Balanced Skip
50 Per Cent Weight of Dumped Skip on Rails
150 Per Cent Nominal Brake Setting
Limit Switch Setting for Normal Stop When Hoisting Loaded Bucket and Lowering an Empty One

per cent for lowering, were used to cover variations due to voltage and load conditions and to the class of motor considered.

A wound rotor polyphase induction motor with the armature short circuited and with normal voltage has a full load speed 95 per cent of no load speed.

It takes one-fifth of a second for a friction brake to begin actual retardation after a stop limit switch has tripped. This assumption makes allowance for the time required to open the circuit to a contactor plus the time for it to drop open, plus the time for the circuit through the contactor to be broken, plus the time required for the brake core to move from the released to the applied position.

The acceleration of the armature and all other moving parts is assumed to require, during one second, 100 per cent of the torque required to hoist normal load at normal speed up the straight part of the shaft.

Voltage will be assumed to be 105 per cent maximum and 90 per cent minimum, and for each condition the particular voltage value will be chosen which tends to make the widest variation in speed. This will mean that the motor speed varies from 95 per cent to 121 per cent of synchronism.

The torque produced by the friction brake will be assumed to be somewhere between 125 per cent and 150 per cent. The value which produces the widest variation in landing accuracy will be used.

From Figs. 12 and 13 it is easy to determine the cage speed at which a hoist can be operated for any desired accuracy of landing. But these curves, as shown by foregoing assumptions, picture the conditions of what might be called an ordinary installation where no refinements were used to improve the accuracy of landing.

The Tables I and II, which refer to Figs. 12 and 13, indicate that much greater accuracy of landing may be obtained by adopting improved methods, as follows:

1. Use a heavier solenoid brake whose maximum retarding torque is 200 per cent of torque required to hoist full load at full speed, and minimum retarding torque is 166 per cent.

2. Provide means in the control apparatus which will eliminate entirely the time interval between the shutting off of power from the motor and the beginning of retarding torque by the brake.

3. Use a motor which has a speed ratio of 2:1, that is, it can be slowed down from a maximum speed to one-half maximum speed before the final stop is made. Such a motor would have approximately 20 per cent more flywheel effect in its armature than would a single speed motor.

4. Use a slip ring induction motor in which all resistance is short circuited while hoisting, thus insuring a range in motor speed between 96 per cent and 114 per cent.

5. Use a slip ring motor, as described under (4), but arrange it with a 2:1 ratio. Such a motor would have approximately 20 per cent more flywheel effect in its armature than would a single speed motor.

Tables I and II indicate by percentage the relative accuracy of these various expedients. The conditions shown by Fig. 12 are taken as 100 per cent for Table I and those shown by 13 are taken as 100 per cent for Table II For example: in Fig. 12, the variation in stopping for a skip whose full load normal speed is 300 ft. per minute will be 6.9 ft. Now by referring to Table I, it will be seen that this condition is considered as 100 per cent, and if the control is arranged to take the lag out of the brake, this variation will be 47.7 per cent of 6.9 ft., or 3.3 ft. If this time element is taken out of the setting of the solenoid brake, and if the brake is increased so that its retarding torque varies between 166 per cent and 200 per cent of normal torque, the variation now becomes 25.3 per cent of 6.9 ft., or 1.74 ft. If a still further improvement is made by using a 2:1 adjustable speed motor having a small slip, and the large brake is still used, the variation will be 6.2 per cent of 6.9 ft., or 0.43 ft. In other words, by introducing several refinements a very high degree of accuracy can be obtained.

As indicated above, one method of improving the accuracy of landing is the use of a 2:1 adjustable speed motor which is slowed down to a creeping speed for approaching the landing point.

There are three other conditions besides accuracy of stopping which will determine the value of this creeping speed, viz.: first, the speed at which the skip may be permitted to enter the dumping horns because of strains in the structure when the vertical velocity of the skip is changed to horizontal velocity; second, the speed at which material may be permitted to spill as determined by its disposition in the receptacle into which it falls; third, the speed at which the skip may strike the scale beam at the bottom when such a beam is used. No attempt will be made in this paper to prescribe these limits because they depend on conditions other than the power drive, but Fig. 11 is submitted as an aid in judging the speed. The accuracy required for landing is most frequently the cause of speed limitation.

Don't use series wound direct-current motors except on Class 1 hoist.

Don't use compound-wound direct-current motors except on Class 1 hoist, unless the series field is short circuited by the starting controller.

Don't insert resistance in the armature circuit of a direct-current motor or an alternating current motor and expect this to improve the accuracy of landing. Under normal conditions it may diminish the speed at which the skip enters the dumping horns, but it increases the variation in stopping accuracy and under abnormal conditions of load, such as hoisting an empty skip and lowering a full skip, it increases the speed at which the skip enters the dumping horns. The only sure method with cylindrical drums * of getting a dependable decrease in speed for dumping and landing purposes is to use dynamic braking or shunt field control in the case of d-c. motors, or multi-speed windings in the case of a-c. motors.

* Conical drums can be made to decrease the ship speed even when motor speed is constant.

TABLE I

FOR CLASS 3 SKIPS

When hoisting an empty bucket and lowering a loaded one the per cent variation from the stopping distance in Fig. 12 is given below:

Motor speed range	2:1			1:1			
Variation from synch.	95 113 Per Cent	95–124 Per Cent		95–124 Per Cent			Per Cent Wt. of Skip on Rails in Dumping
Brake per cent	150 125	200 166	150 125	150 125	200 166		
Percentage variation from Fig. 12			18	72.		A	0
	9 43			41.	22.6	B	
			30	100.		A	50
	17.	6.2		47.7	25.3	B	
			31	102.		A	75
	31.5	7.73		53.3	28.1	B	

A indicates variation allowing 0.2 seconds after power shut off before brake applies.

B indicates variation when braking commences instantly after power cut off.

TABLE II

FOR CLASS 3 SKIPS

When hoisting an empty bucket and lowering an empty one the per cent variation from the stopping distance in Fig. 13 is given below:

Motor speed range	2:1	1:1			
Variation from Synch..	95–124 Per Cent	95–124 Per Ceat			Per Ct Wt of Skip on Rails in Dumping
Brake per cent	150 125	150 125	200 166		
	9.76	54.7		A	0
		41.3	22.7	B	
	9.88	100.		A	50
				B	
	24 3	113.		A	75

A indicates variation allowing 0.2 seconds after power shut off before brake applies.

B indicates variation when braking commences instantly after power cut off

In order to render these skip hoists automatic in action, it is necessary to use full magnetic control, and along with this should be provided overload protection. Sometimes no-voltage protection is also necessary, but in other cases it is perfectly proper for the skip to resume operation as soon as power is restored. In the case of a-c. motors protection should be provided against an accidental reversal of the phase rotation in the power supply. This can be done either by the use of a reverse-phase relay or by special arrangement and connection of limit switches. Some trouble may be encountered from a reversal of incoming power, as the skip may start down with a wrong condition of load and this may cause trouble, or it might injure someone who had every reason to believe that the skip was going to start in the normal direction and had placed himself in a dangerous position. A phase reversal relay will protect against either of these troubles. Another trouble is that the usual method of connecting limit switches protects against over-travel only when the normal up contactor will stop the cage from going in the up direction, but under conditions of phase reversal the up contactor would not control the motion of the up direction. Consequently an elaborate arrangement of limit switches or a phase reversal relay is required to protect against such an emergency. A slack cable switch for stopping the hoist, should a cable become slack around the drum indicating that it was broken or that a skip had been obstructed in the shaft, would protect against trouble.

Automatic control may be made to perform any of the following functions:

(a) An attendant starts the skip from the bottom and it is hoisted to the top where it is automatically dumped and stopped. It does not move again until an attendant starts it, and it goes through this cycle each time an attendant starts it. Such an equipment requires a push button for starting up, a push button for starting down, a stop switch, and the necessary limit switches for slowing down and stopping at each end of travel.

(b) On Class 1 and Class 2 hoists, it is often advantageous for the operator to start the skip from the bottom and for the skip to make a round trip before the operator is again required to give it attention. Such a controller requires a push button for starting up, a push button for starting down (to be used only in cases of emergency or try-out), a stop switch, a time element relay for holding the motor at standstill for approximately five seconds at the top while the skip is being dumped, and limit switches for slowing down and stopping at each end of travel.

(c) On all classes of hoists it is sometimes advantageous to have a means of starting the skips into operation and having them run continuously without further attention, with approximately five second intervals at each end of travel for loading and unloading. Such a controller would require a starting up push button, a starting down push button, a stop switch, necessary time element relays and limit switches for slowing down and stopping at each end of travel.

(d) Class 1 and Class 2 hoists sometimes require a five second interval for unloading at the top, and an automatic switch connected with a scale beam for starting the skip at the bottom. Such a hoist will run continuously when once started and will automatically dump and reverse at the top, and will remain at the bottom on a scale beam until a predetermined weight of material is spilled into it, whereupon it automatically is hoisted to the top. Such a controller requires a starting up push button, a starting down push button, a stop switch, time element relay, master switch operated by a scale beam, and the necessary limit switches for slowing down and stopping at the end of travel. It is also necessary that there be a certain amount of slack rope leading to the bottom skip when it first rests on the scale beam so that the solenoid brake on the motor shaft will not interfere with the descent of the skip as its weight increases. (As stated above, the curves plotted to show variation in stopping were not made to cover the use of a scale beam.)

(e) On Class 3 hoists it is sometimes desired to have the hoists operate continuously when once started, their operation to be governed by a scale beam at the bottom of each shaft—one scale beam starts one of the skips up when loaded, and the other scale beam starts the other skip up. In addition to this, a time element relay might be inserted to hold the motor at standstill not only while the scale beam is operating, but for a pre-determined time of about five seconds so as to make sure that the top skip has been fully emptied. Such a controller would require a starting up push button, a starting down push button, a stop switch, two master switches which are operated from scale beams, necessary time element relays if desired, and limit switches for slowing down and stopping at each end of travel.

A necessary part of all of the above control apparatus is that the motor be equipped with a solenoid brake; but under one special condition it is possible to operate a skip hoist without a solenoid brake, and this on a Class 1 hoist, although this is not always to be recommended on account of other disadvantages; for instance a brake of some kind may be needed when repairs are made. A series wound d-c. motor can be used for hoisting, and if the hoisting speed is such that the material is fully dumped at the time the skip reaches the top of travel, the motor can be allowed to reverse immediately and descend by dynamic braking using a normally closed contactor. Stopping at the bottom can be obtained by decreasing the dynamic braking resistance and then allowing the skip to settle at very slow speed onto a positive foundation at the bottom. When shunt wound direct-current brakes are used, a centrifugal switch or some protective relays are needed to prevent the current regenerated by the motor from sustaining the brake in case power fails. A sustained brake would allow the motor to overspeed.

Extension of Electric Power Service Into the Oil Fields

By W. G. Taylor

Power and Mining Engineering Department, General Electric Company

W. G. Taylor

THE chief developments in oil field electrification have taken place in California, Kansas, Texas, and Oklahoma, where favorable conditions for the introduction of motors on a large scale have been produced by the existence of adequate power systems within reach of the fields. Electric power, mostly from small isolated plants, is also being used in several scattered instances in the fields of West Virginia, Pennsylvania, Louisiana, Illinois and Wyoming.

California

In California the oil fields in the San Joaquin Valley, Fig. 1, are all served by the San Joaquin Light and Power Corporation or its subsidiary, the Midland Counties Public Service Corporation. The latter reaches the Coalinga field in the valley, and the Santa Maria field on the coast. The valley fields were the first in this country to adopt modern oil well motors extensively. This change from the long established use of steam and gas engines was assisted to some extent by the low power rates made possible by the fact that a large part of the power is hydroelectric. The principal plants are on the San Joaquin River, northeast of Fresno, smaller ones also being located on the Tule River farther south and on the Kern River near Bakersfield. These have a total capacity of 57,000 kv-a. Two steam plants near Bakersfield with 45,000-kv-a. capacity and one on the coast near Santa Maria with a capacity of 2,000 kv-a supply additional power as well as some held in reserve.

Fig. 1. Oil Wells Pumped by Electric Power in the Midway Oil Field, Calif.

Three main transmission lines extend south through the valley. The one on the west side, which passes through the principal oil fields in the valley, is a 66,000-volt line with an approximate length of 190 miles. The 66,000-volt line of the Midland Counties

Public Serv[illegible] branches from a[illegible] at Hemet [illegible] the west over the Mount [illegible] [illegible] and south to [illegible] a distance of 180 miles. [illegible] Valley operates [illegible] 120 miles in [illegible]. The [illegible],000-volt line is [illegible] and terminates [illegible] Bakersfield. The [illegible] west lines are tied together [illegible] Bakersfield and the center [illegible] McKittrick, thus forming a double [illegible] system which [illegible] for the extensive [illegible] McKittrick and the Kern River field at Bakersfield. The three transmission lines are also connected by additional [illegible] lines farther north.

All primary distribution is at 11,000 volts, [illegible] circuits being used wherever practicable, the total length of any circuit not exceeding [illegible] miles. Field transformers step the voltage down to 440.

The approximate average load of the various fields at present is as follows:

Midway and adjoining fields	10,000 kv-a.
Kern River field	7,000 kv-a.
Coalinga field	4,500 kv-a.
Santa Maria field	4,[illegible]00 kv-a.

As the power-factor of the average oil field load is rather low, varying between 60 per cent and 70 per cent, a 3,000-kv-a. synchronous condenser has been installed near Santa Maria on the line of the Midland Counties Public Service Corporation, and a 4,000-kv-a. unit will soon be installed at Taft on the west side line of the San Joaquin system.

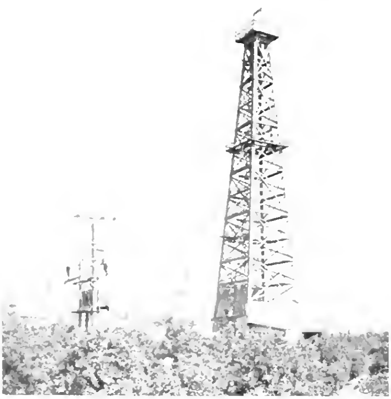


Fig. [illegible] Me[illegible] Rotary Drilling Rig of La Merced Oil Company, Montebello, Calif.

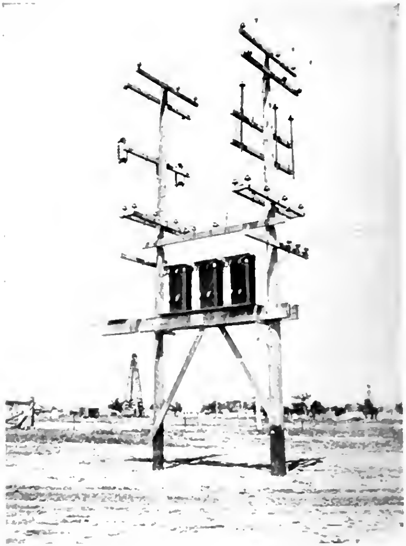


Fig. 3 A Typical Transformer Installation Made by the Empire Gas and Fuel Co. for Oil Well Pumping in the El Dorado Field, Kansas. The bank consists of three 25-kv-a. units, stepping the voltage down from 12,000 to 440

These power systems have of course required great expansion to carry this growing load as well as that of other industries, particularly irrigation, which have built up rapidly in recent years; and the projects under way as well as those planned for the future will ultimately more than double the present total capacity.

In southern California about 250 electrified wells furnish the present oil field load. Electric drilling, Fig. 2, is being taken up in this region to a rapidly growing extent. Energy is supplied by the Southern California Edison Company and is largely hydroelectric power generated in the Sierra Nevada Mountains about 250 miles from Los Angeles. The present transmission voltage is 150,000, but this will soon be raised to 220,000 volts. Additional power is obtained from oil-fired steam stations. The entire system has a total generating capacity of over 270,000 kv-a.

A complex distribution system serves the oil fields, where field transformers step down the various primary voltages to 440 volts. An interesting feature of this system is the frequency, which is 50 cycles. Several other smaller power companies, all but one operating at 60 cycles, are tied in with the Edison system through frequency-changer sets.

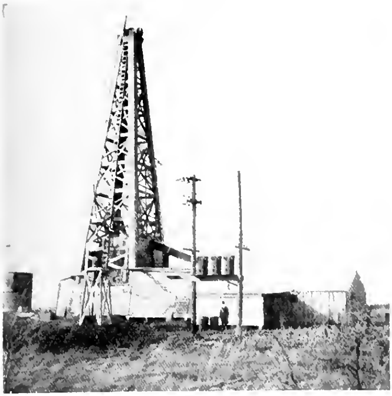


Fig. 4. This Well is being drilled by the Roxana Petroleum Co. with motor-operated cable tools, power being received from Guthrie, Okla., over a $6\frac{3}{4}$-mile, 6600-volt transmission line which the Company built and operates to save the expense of hauling fuel for steam drilling

Kansas

In the Mid-continent oil fields, Kansas offered the first opportunity for electrification on a large scale, as the lines of the Kansas Gas and Electric Company were within easy reach of the El Dorado and Augusta fields and now extend to the newer Elbing and Peabody fields. El Dorado and Augusta are only about 35 miles northeast from the main generating plant at Wichita, and the other fields are about the same distance farther to the north, but the entire 60,000-volt transmission system has a total length of lines of approximately 175 miles. A portion of the system between Wichita and the fields constitutes a loop which assists in the maintenance of continuous service. Primary distribution is at 11,000 volts and secondary distribution at 440 volts, as on the San Joaquin system in California.

The Wichita generating station is a 30,000-kw. steam plant using oil, gas, and coal for fuel. The total oil field load now carried is approximately 5200 kw., of which 4,000 kw. is in the El Dorado and Augusta fields.

The Empire Gas and Fuel Company, which has carried out in the El Dorado field the most extensive electrification of any oil company in this country, purchases its power from the Kansas Gas and Electric Company at 60,000 volts and steps it down to 12,000 volts for primary distribution and 440 volts for the motor circuits, Fig. 3. Their substation at present has a capacity of 3,000 kv-a., but is designed for and will eventually be increased to 6,000 kv-a. A 2500-kv-a. synchronous condenser located at this substation will make the ultimate capacity approximately 4800 kw. at about 80 per cent power-factor. This company has over 500 oil well motors in operation and has adopted electric drive for all its drilling in the El Dorado field.

Oklahoma

The only hindrance to the more rapid adoption of motor drive in all oil fields during the last two or three years has been the lack of available generating capacity on the part of the central stations. This has been the case in Oklahoma, where so far only a few oil leases are operated electrically, Fig. 4. However, the Oklahoma Gas and Electric Company, which has lines within reach of two-thirds of the fields of the State, is not only in

Fig. 5. Electrically-pumped Oil Wells in the Goose Creek Field, Texas

a better position this year to supply the demand but plans to increase its plant capacity materially in the near future. The oil field load, now approximately 700 kw., bids fair to compare favorably in size in the near future with that of any other central station in the country. Steam plants are located at Oklahoma City, Enid, Drumright, Sapulpa, and Muskogee, and other plants at Sand Springs and Tulsa are tied into the system, making a total present capacity of 33,000 kw. Oil and gas are the fuels used, as no water power is available.

A[illegible] [illegible] lines are in two divisions, each about 100 miles in length and both operated at 66,000 volts. No loops have yet been constructed but several are under consideration. The Eastern Division extends through the famous Cushing and Glenn pools [illegible] from Drumright through Sapulpa [illegible] east as Muskogee. The Western Division runs from Norman through Oklahoma City to El Reno and then north to Enid and the Garber-Covington oil field. Further extensions are being made. For serving the fields a primary distribution voltage of 13,200 is used, stepped down to 440 volts at the leases. One exception is the Garber-Covington field, which has 4000-Y volt primary distribution.

The oil fields in Eastland and Stephens Counties in the west central part of Texas are served by the Oil Belt Power Company, from a 6,000-kw. steam plant on the Leon River, tied in with a 900-kw. steam plant at Eastland, 400 kw. at Ranger and 200 kw. at Breckenridge. The Leon plant was only recently completed and the oil field load so far is not over 1,000 kw. but electrification in this district has practically only just begun. All the plants use oil for fuel, those at Ranger and Breckenridge being oil-engine driven. The Leon and Eastland plants are connected to Ranger by a 12,000-volt looped distribution system which covers the Ranger field, while from Leon a 28-mile 60,000-volt line runs to the Breckenridge field. The voltage at the motors is 440.

TABLE I

ISOLATED ELECTRIC POWER PLANTS IN THE OIL FIELDS

Over 100 kv-a.

[illegible]	Location	Kv-a Capacity	Prime Movers
H[illegible] Oil & Refining Co.	Goose Creek, Texas	2500	Steam turbines (oil and gas fuel)
Gulf Production Co.	Goose Creek, Texas	1875	Steam turbines (oil and gas fuel)
Humble Oil & Refining Co.	West Columbia, Texas	1250	Steam turbines (oil and gas fuel)
Magnolia Petroleum Co.	El Dorado, Kansas	1200	Oil engines
Louisiana Consolidated Oil & Refining Co.	Hosston, La.	1025	Steam engines and turbines (oil and gas fuel
South Penn Oil Co.	Folsom, W. Va.	960	Gas engines
Republic Production Co.	Hull, Texas	625	Steam turbines (oil and gas fuel)
Cosden Oil & Gas Co.	Shamrock, Okla.	540	Gas engines
Coastal Oil & Fuel Corp.	Jennings, La.	225	Oil engines
Rio Bravo Oil Co.	Saratoga, Texas	187	Steam engines (oil and gas fuel)

Texas

The recent oil booms in Texas have done much to awaken the power companies to the possibilities of load which the oil industry affords. In the northern part of the State, the Wichita Falls Electric Company extended its lines into the Burkburnett pools and has taken on an oil field load of about 3700 kw. This load will continue to grow, as only a small percentage of the wells are now pumped by motors. Power is transmitted at 22,000 volts from the city of Wichita Falls approximately 25 to 30 miles to the fields, the service being protected by a loop system. Another line 25 miles in length reaches the older Iowa Park and Electra fields, but the oil field load there is now small. Primary distribution is at 4160 volts, stepped down to 440 volts at the wells. All the power is generated in a 10,900-kw. steam plant at Wichita Falls, using oilfor fuel.

Except in the Spindletop field, where the Beaumont Electric Light and Power Company serves a number of leases for oil well pumping, no central station power is available in the Gulf Coast pools, and consequently the oil companies which have installed motors have built their own plants or rely upon neighboring companies for power. The Goose Creek field, Fig. 5, has two such installations, and there are a number of others in various fields, these being listed in Table I. Plans under consideration by these and other oil companies indicate that several additional isolated plants will soon be built, the investment beihg well warranted by the increase in prodvction and thee large reduction in the cost of operation effected by a genera! electrifiaation of the leases.

Load Conditions in the Glass Industry

A USER BUT NOT BUYER OF ELECTRIC POWER

By C. W. Fick

Power and Mining Engineering Department, General Electric Company

C. W. Fick

THE glass industry has not been a large purchaser of central station power. Not that there is any question about the application of electric motors to the various drives; on the contrary some of the complex glass product machines would require an entirely different design were not motors available, and in the manufacture of plate glass the grinding and polishing time would be increased were not available the quick starting and stopping by electric motors. Neither is it because the glass manufacturers have not realized the economies and advantages resulting from electric drive, for, according to the 1914 census report, 54 per cent of the primary power is transformed to electric power.

The reason is that the industry has been generating its own power. In 1914 the installed horse power was approximately 93,000, 20 per cent of the power for which was purchased and the remainder generated at the plants. It is estimated that in 1920 the total installed horse power was about 150,000, for which 25 per cent of the power was purchased.

Why have not glass manufacturers purchased more of their electric power? A cheap fuel supply (natural gas, or coal for making producer gas) has determined the location of glass making establishments; hence we find Pennsylvania, Ohio, Indiana, and West Virginia producing 75 per cent of the glass made in the United States, with Pennsylvania's output alone constituting 33 per cent of the total.

With cheap fuel for the melting furnaces and annealing lehrs in his plant, is it strange that the manufacturer should use it for his power source? The use of gas engines, either for driving generators or in some cases for direct application to the process, was a very natural result.

But the natural gas supply is failing. Indeed in some sections it has already disappeared. In others its use for industrial purposes has been greatly curtailed. The glass engineers are making preparations for an alternative power supply.

General Load Conditions

Regarding the magnitude of the load, it was stated above that in 1914 the installed electric horse power was 93,000, and an estimate for 1920, 150,000. The ratio of average load to installed power is about 60 per cent, making the average load in the neighborhood of 80,000 kw., or the average continuous output of 90,000 h.p. for the latter year. As in most industries where fusion of the product is involved, the plants operate 24 hours per day, and the average number of days per year is 280. Thus the annual consumption of electric power is 500,000,000 kw-hr., not a large load in comparison with that of many other industries, but considering the localized condition it is certainly worth consideration.

In 1920 there were about 340 glass manufacturing plants in this country; thus the average installed power per plant is 440 h.p.

The load is practically all alternating-current power, affording economical transmission and transformation to any desired voltage. The applications are as a rule constant speed, or if varying speed the variation is required but a small part of the time, making possible the use of the sturdy and easily controlled induction motor.

The shape of the load curve depends on the product; for some of the bottle works and window glass factories it is usually quite uniform, while for the plate glass plants it may at times be uniform and at others very irregular. The reasons for this irregularity will be explained later.

There is little choice with regard to frequency, sixty cycles having a slight advantage because of the greater choice of speeds and lower cost of apparatus. If 25 cycles only is available, however, it will usually be more economical to use motors of that frequency than to purchase frequency-changing apparatus.

The products of the industry may be divided as follows:

- Building glass (including plate, window, wire, and obscured).
- Pressed and blown glass (such as lamp globes, table ware, shades, etc.).
- Bottles and jars.

By far the largest users of power are the plate glass plants. They form less than ten per cent of the glass manufacturing establishments in number but consume nearly 70 per cent of the total power. A brief outline

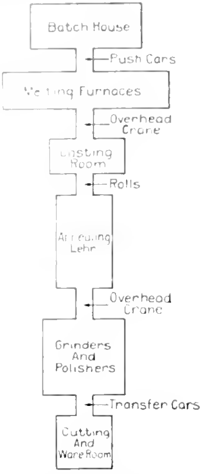


Fig. 1. Schematic Diagram of the Sequence of Processes in Plate Glass Manufacture

of the processes in this branch of glass manufacture will afford a better idea of the power requirements.

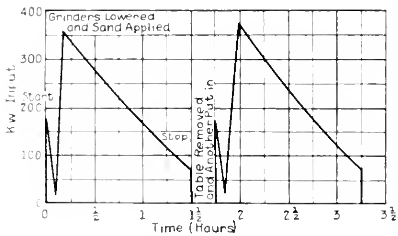


Fig. 2. Typical Duty Cycle Load Curves for the Grinding Operation

Process of Plate Glass Manufacture

Referring to the chart of sequence of processes, Fig. 1, the primary constituent materials—sand, limestone, and soda ash in the proportions of 100, 25, and 35—are thoroughly mixed in the batch house.

Mixers requiring 15 to 30 h.p. are used for this work. Push cars or conveyors transfer the batch to bins in the furnace room, and hand operated ladles dip it into the melting pots. The volume of the mixture is so reduced by fusion that three pots of batch are required to make one pot of glass. The temperature of fusion is about 2600 deg. F.

The clay pot of molten glass is carried by an overhead crane and balanced tongs to the casting table upon which it is poured and rolled into sheets about 18 ft. square and one-half inch thick. Live rolls carry the sheets into the lehr or annealing oven, a long tunnel-like room the entrance end of which is heated by gas to the temperature of the cherry red glass. Revolving grates pass the sheets slowly through the lehr (each section of which is at a lower temperature than the preceding one) bringing them after about four hours to the cold end.

So far in the process the motor applications have been only small crushers, mixers, cranes, and revolving grate motors. The next steps, grinding and polishing, are where the largest amounts of power are used. The plates, large ones which came from the lehr whole and perfect, and small ones which had to be broken because of strains resulting from unequal cooling, are placed on a flat circular table, 20 to 36 ft. in diameter, covered with quick drying plaster of paris. The table is moved on a transfer car to a motor driven spider. The motor is started and cast-iron shoes are lowered on the revolving table of glass. With the

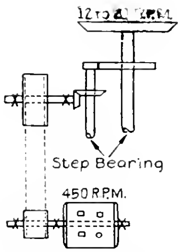


Fig. 3. Layout of Motor Drive Mechanism

aid of sharp sand the rough surfaces of the glass plates are ground off. At first coarse sand is used, but as the high spots disappear finer sand is applied and the pressure on the shoes decreased. Fig. 2 shows a typical duty cycle of the grinding operation, and Fig. 3 the mechanical arrangement of the motor and driving mechanism.

The polishing mechanism is similar to the grinding arrangement, except that felt pads and rouge replace the iron shoes and sand, and gives the glass surfaces a highly polished finish.

Fig. 4 illustrates the power cycle of the polishing motor. These curves explain the variation in the plant load curve, for, as there are sometimes 16 or 18 of these polishers and grinders in a single plant, should their rest periods coincide an uneven load would result; but if the rest periods are properly "staggered" a uniform load is maintained.

The approximate power requirements for tables of various sizes are shown in Fig. 5, varying of course with conditions of peripheral speed and pad or shoe area.

The starting torque for grinders and polishers is only 30 to 40 per cent of normal running torque. Because manufacturers have deemed it necessary to operate the tables at a reduced speed the first 10 or 15 minutes of each operation, slip-ring induction motors have been used. This low-speed operation increases the time required for the operation and there is a tendency toward bringing the table immediately to top speed, and with this condition squirrel-cage or synchronous type machines could be applied advantageously.

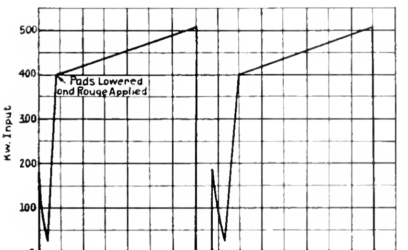


Fig. 4. Typical Duty Cycle Load Curves for the Polishing Operation

Magnetic control is recommended for the polisher and grinder motors, for it makes the operation less dependent on the attendant, and because such control is designed better to meet the sometimes frequent jogging required for spotting the tables on the tracks.

Many applications for pumps are found in a plate glass plant: Water pumps for fire protection, engine room, and cleaning purposes; plaster pumps for the tables; and sand pumps for the grinders.

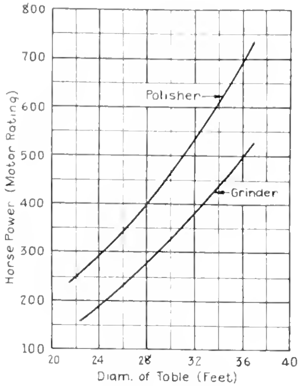


Fig. 5. Approximate Load Requirements for Various Size Tables

The following tabulation shows the principal motor applications with the proportion of total power which each requires:

Polishers	45 per cent
Grinders	35 per cent
Pumps	10 per cent
Compressors and fans	5 per cent
Conveyors, cranes, and hoists	2 per cent
Mixers and agitators	2 per cent
Miscellaneous	1 per cent

If properly motored the power-factor may easily be maintained at 80 per cent or better.

Future developments in the glass industry, insofar as the electrical world is concerned, lie along the lines of direct-connected motors for the grinders and polishers in the plate-glass branch, and of electric furnaces and annealing lehrs in all branches. Fig. 3 shows the heavy, expensive, and inefficient construction resorted to for operating the tables, to better which the proposition of a direct-connected motor of the induction or synchronous type is being seriously considered. Such a drive will require much less space than the present arrangement, will eliminate the power consuming and expensive gears, with their necessary construction work, and will minimize the number of spare parts required to insure continuous operation.

The possibilities of the application of electricity to process work is being realized, and already an electrically heated plate glass annealing lehr is in successful operation. The importance of correct and accurate temperature control of the lehr is evident from the fact that on some days the breakage due to uneven or improper cooling runs as high as 80 per cent. The control for electrically heated lehrs and ovens can be made entirely automatic so that, once adjusted, the results are perfectly uniform.

With the advent of a commercial glass melting furnace which can compare in cost with the present tank or pot furnace, the failing gas or oil supply will not be the serious proposition for the industry that it is today.

Electric Drive for Flour and Grist Mills

By W. T. Edgell, Jr.

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W. T. Edgell, Jr.

It is estimated that the power required by the milling industry in the production of flour and grist mill products in the United States is approximately 900,000 h.p. This figure applies only to merchant mills, that is, mills in which the grain is purchased, manufactured into flour, and then sold to the consumer. It does not include either the small custom mills which grind for toll or the large number of grain elevators in which the grain is cleaned, dried, mixed or stored for trans-shipment, but in which no grinding operation is performed. Only 15 per cent of this power is applied by electric motors, but approximately 50 to 60 per cent of the total milling capacity is within easy reach of central station service. Steam and water power have shown a decreasing proportion since 1904, but in 1914 these two classes of power represented 76.9 per cent of the total reported for the industry. The use of electric power has shown a steady increase from two per cent of the total in 1904 to approximately 15 per cent in 1917. The power requirements of the average mill are not great, the average installed horse power being about 75, but nearly every central station has one or more possible power consumers in this industry.

The milling of flour of the quality required by the present-day consumer is a complicated process necessitating 40 or 50 distinct operations. These operations must be performed in definite sequence through a continuous process. Fig. 1 illustrates on a small scale the fundamental sequence of operations.

The preliminary cleaning and storage of the grain is distinct from the milling operation. The grain as received from the wagon or car is dirty and mixed with miscellaneous seeds and foreign matter. It is dumped into a bucket elevator leg, carried to the storage bins, and then fed by gravity into the separators. In the separators it passes through suction legs where light impurities are removed. The grain is then treated by a series of sieves for the separation of straw, stems, unthreshed heads, thistles, corn, cockle, mustard, sand, etc. One set of sieves removes all material larger than the wheat. Another set will remove material that is smaller and possibly a third set will depend for its separating action on the shape of the seed it is designed to remove. After all of the impurities have been removed by the screening and suction processes, the wheat berries are carried into a scouring chamber where dirt, smut, and fuzz are brushed from the wheat and carried off by a strong blast of air.

The cleaned wheat is then tempered or conditioned by steam or water to toughen the bran and to make all the berries of the same hardness.

After being cleaned and tempered the wheat goes through the roller mills. The object now is to separate the germ and bran from the flour component. After the berry is broken by the corrugated breaking rolls it is passed through smooth reducing rolls which flatten instead of cut the material, thus making it possible to screen out the minute flakes of bran, germ, etc., while the finely powdered flour passes through the bolting cloth. The material passes through several sets of breaking and reducing rolls and between each passage the product is screened or bolted because it is possible at various stages of the process to divert a certain amount of finished product directly to the flour bins or to discard other parts because their flour content is so small that further processing is useless. The resulting products are flour, bran, and shorts.

The foregoing description of the process applies only to the essential operations in flour milling. Many mills grind feed, corn, rice, barley, rye, etc., in addition to wheat flour, and in each mill the process differs in some detail. The power requirements of a given mill will depend largely upon the grade of flour that is being manufactured, the type of machinery used, as well as upon the milling operations which are being performed on other grains.

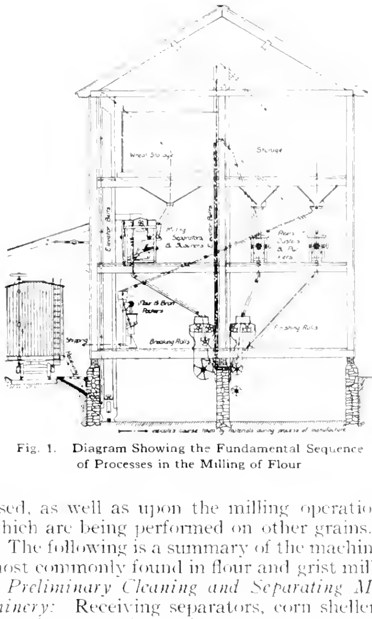

Fig. 1. Diagram Showing the Fundamental Sequence of Processes in the Milling of Flour

The following is a summary of the machines most commonly found in flour and grist mills:

Preliminary Cleaning and Separating Machinery: Receiving separators, corn shellers, oat clippers, cockle cylinders, scalpers, scourers, smutters, washers.

Grinding Mills: Roller mills, buhrstones and other stones, corn crushers, scroll mills, iron stones, attrition mills, impact grinders, miscellaneous type farm feed mills, hullers, and degerminators.

Cleaning and Purifying Machinery: Aspirators, reels, plan sifters, bolters and gyrators, purifiers, bran and shorts dusters, bleachers.

Conveyors, etc.: Car shovels, elevator belts, conveyor belts, screw conveyors, packers.

The majority of the smaller mills are at present being driven by steam engines. Very little steam is used for process work and in most of these installations the size of the engine and available water supply does not warrant a condensing equipment. Such an arrangement is not generally economical. Furthermore, the usual layout provides for one engine to drive the entire mill, which means heavy line shafting with consequent increase in fire hazard from over-heated journals due to faulty hanger alignment, accidental distortions, or imperfect lubrication. Such installations require a large number of belts with correspondingly high maintenance losses, as well as a tremendous friction loss in the transmission system.

It should be remembered that grain dust is highly explosive and the ordinary steam engine drive necessitates either a boiler room dangerously close to the mill or the alternative of heavy transmission losses in rope drives or steam mains. The presence of a boiler room, unless it is installed in a fireproof building, increases the insurance rate from approximately 15 per cent in the case of stone or brick mills to 50 per cent in the case of frame buildings above the normal charge for properly electrified mills. The insurance charges are under most conditions considerably less for motor-driven than for steam-driven mills.

Water power is depended upon to a great extent in the smaller plants. The more evident disadvantages are the limited amount of power available which generally requires supplementing by some other power, reduced capacity with possible necessity of shutdown during the dry season and low water, and possible troubles due to backwater in the tailrace during flood seasons. These troubles, high maintenance cost of shafting and belts, as well as poor speed regulation, offer sufficient reason in many cases to change over to electric drive or to adopt it as reserve or breakdown service.

The use of electric motors makes it possible to sub-divide the machines in such a way as to eliminate a large part of the friction losses in the transmission. The fire danger is reduced because there are fewer bearings to overheat and less danger of the inflammable dust coming into contact with a burning flame. It is possible to operate the receiving and cleaning machinery without driving the flour milling machinery, and the packers, [illegible]sts, car pullers, [illegible] etc., need only be operated when [illegible] actual need for them. It is estimated [illegible] per cent variation in speed is the [illegible] mills producing the best grades of flour. [illegible] elimination of belt slippage [illegible] system, motor-driven

TABLE I

[illegible]	HORSE POWER REQUIRED	
	Soft Wheat	Hard Wheat
50	22	27
60	26	31
75	32	37
100	40	45
125	46	54
150	54	62
200	66	80
250	77	98
300	87	108
400	115	138
500	143	175

groups of machines are kept more closely to their rated speed thus increasing the output as well as improving the quality of the product.

Practically all motors used in flour mill work are of low or moderate speed and are designed for constant-speed service. The dust which pervades the mills is oily and tends to pack into the crevices in the frames and insulation thus interfering with ventilation. This dust is also highly inflammable when in suspension in the air. Squirrel-cage motors and wound-rotor motors with enclosed collectors may be used in relatively clean locations, but it is preferable in all dusty locations to use enclosed ventilated motors, or if possible to enclose the motors in separate well-ventilated dust-proof and flash-proof compartments. The wiring should be in conduit, the motor connections should be made through conduit terminal boxes, and the fuses and switches should be enclosed in dust-proof cabinets. The use of electric lights is a decided improvement over any other type of lighting, but explosions have been attributed to the breaking of a lamp bulb when in a dust-laden atmosphere, and it is advisable in all cases that the lamps should be provided with proper guards.

The use of electric power allows a very flexible arrangement of drive. The milling process is continuous and provision must be made so that the product will pass through the successive operations automatically; and if any machine, elevator, or conveyor stops, all previous operations in the sequence should stop to prevent clogging the system. The milling machinery may be driven from one motor, or unit operation may be effected by bringing the control of a complete section to a common panel and so wiring it that the motors can be started either at once or in a predetermined sequence and so that if one motor stops all other motors preceding it will stop also. If a single motor is used without a friction clutch for group drive it should be of the slip-ring type if alternating-current or compound wound if direct-current, but if a friction

TABLE II

Horse Power Installed	Number Motors	Running Hours Per Week	Average Kw-hr. Per Month	Maximum Kw-hr Demand	Average Kw-hr. Per Month Per Connected H.P.
25	2	30	758		30.3
40	1	24	570	25	14.2
40	1	60	3860	31	97.0
50	1	65	3450	21	69.0
50	1	66	2600		52.0
50	1	66	4250		85.0
60	1	66	8000		133.3
83	5	60	5990		72.2
105	3	48	5660	80	54.0
105	2	144	27857		265.0
110	3	66	9880	75	90.0
120	2	60	16670	90	139.0
150	2	54	15700	94	105.0
150	1	60	34096		227.0
200	2	144	50000	145	250.0
265	6	66	31666	196	119.7
265	2	120	50000	170	189.0
300	1		123882		413.0
320	4	18	55100		172.0
380	8	72	20000	90	52.5
820	23	144	199672	413	243.5

clutch is used the motor may be either of the synchronous or squirrel-cage type.

Duplicate systems, parallel processes, receiving elevators, separating and scouring machinery, packers, hoists, fire pumps, and fans may all be driven in separate groups, thus increasing the efficiency of the plant.

With either the single motor or subdivided drive, push-button stations should be located at convenient points so that an entire mill section may be stopped from any one of them.

Table I shows the average installed horse power required for flour mills using one main driving engine or motor with the consequent large amount of shafting and belting. The power requirements of the receiving or cleaning machines are not included but the figures given do include grinding, auxiliary bolting, and elevating machinery. The values vary considerably but will serve as a guide in checking estimates based on actual layouts.

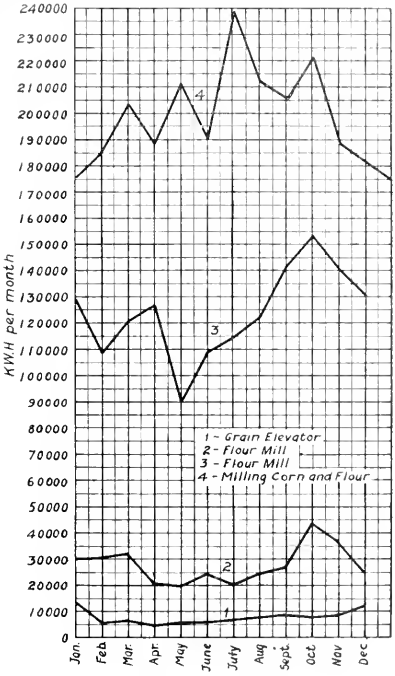

Fig. 2. Curves of Seasonable Distribution of Load in Flour Mills and Grain Elevators

For mills above 500 barrels capacity which are well planned but which use the single motor drive, $3\frac{1}{2}$ barrels capacity per horse power would be estimated for soft wheat and three barrels per horse power for hard wheat. In the more modern mills with

Fig. 3. Panels for Controlling 46 Motors in an Electrified Terminal Elevator

individual or sub-divided group drive, a fair estimate would be one horse power for each $3\frac{1}{2}$ barrels per 24 hours capacity in mills rated at less than 1000 barrels, and one horse power to four barrels capacity in the larger mills, excluding of course the receiving and preliminary cleaning machinery.

For cereal mills manufacturing hominy, corn meal, etc., a good checking figure is based on two horse power installed for each bushel per hour capacity up to 100 barrels per hour. For larger mills this figure would be approximately $1\frac{3}{4}$ horse power per bushel per hour.

It is difficult to predict the current consumption per barrel of flour unless the mill layout is known, but with a very efficient properly divided electric drive in a new mill it should be possible to reduce the power consumption to four kilowatt-hours per barrel. In well-designed mills a figure of four to six kilowatt-hours per barrel has been attained, but in the ordinary small mill the [illegible] varies between [illegible] hours [illegible] H were obtained [illegible] and will be of inter- [illegible] mills grinding [illegible] being a combination [illegible] It will be noted that [illegible] installations indicates [illegible] power consumption per [illegible] 1650 kilowatt hours [illegible] seasonal distribution of [illegible] mills and grain elevators [illegible] which are used to [illegible] and clean various grains [illegible] is particularly applicable [illegible] elevators the drives may be so [illegible] each machine and each con- [illegible] driven by its own motor. [illegible] decided saving in power, [illegible] and construction costs, and [illegible] reduces the fire hazard.

These features can be illustrated by the following data relating to one terminal elevator: The elevator itself is 73 ft. wide, 269 ft. long and 185 ft. high. The distance from the elevator to the motor in the farthest tower is approximately 1200 feet. The total installed horse power is 2215, but 1045 horse power is installed on the top floor 175 feet above the ground. Fig. 3 shows the central controlling panel for the 46 motors. All of these motors are started by one attendant in response to signals from the machinery operators, and push buttons located at convenient points throughout the elevator make it possible to shut down any motor with consequent automatic shutdown of all motors, the continued operation of which would clog the system or pile up the grain. It is evident that the successful operation of an elevator of this type is rendered possible only by the use of motor drive.

Electric Shovel Load Characteristics

By D. Stoetzel

Power and Mining Engineering Department, General Electric Company

D. Stoetzel

The modern electric shovel is not a new or untried application of electric power to this severe service. Ten years ago the electric shovel was looked upon as an experiment and was considered an impossibility; but the first shovels, although lacking in the finer details, proved conclusively that they had [illegible] a new and very promising field for motor application. Today this regard of electric shovels has changed, as is evidenced by the large number of such shovels in successful operation and the growing tendency toward their use.

This change in attitude has been largely due to the increased cost of coal, which has forced the operator to seek cheaper means of operating the shovel. Naturally he turned toward the electric shovel which he had shunned for so many years, and his investigation led him to recognize its many advantages, which had always existed but had been previously overlooked.

It must not be inferred that the electric shovel is not a paying investment except where fuel is expensive, because a good saving in operating expense has always been possible even where coal is obtainable at a ridiculously low figure. As a matter of fact, a large number of these shovels are operating in the coal fields where an unlimited coal supply is available beneath the shovel trucks.

There can be no doubt that the electric shovel, when furnished with the proper electrical equipment, becomes a desirable power system load. There have been some complaints regarding power peaks on shovels having alternating-current motor equipment but this condition can be readily overcome as will appear in the following explanation. The majority of the shovels operate on a ten-hour shift, both day and night, and some operate continuously, shutting down only for oiling, adjustments and repairs. Electric shovels are also capable of operating all the year round, not being affected by severe cold weather as is the steam shovel.

There is little doubt that direct-current motors have a decided advantage over alternating-current motors for all-around shovel work. Alternating-current motors, used in connection with transformers, simplify transmission problems. On the other hand, they do not give as good operating characteristics as direct-current motors and require larger motors for the same work. The alternating-current shovel as a unit will tend to be slower or the power peaks will be considerably higher. Consequently the cost of operation will be increased. Direct-current motors greatly increase the power transmission problems but afford better operating characteristics. In fact, the series-wound direct-current motor can approximate or even exceed the steam engine characteristics which are admitted to be very good for this service. The transmission difficulty is best remedied by providing a 2300 or 4000-volt synchronous motor driving individual differential-wound generators, one for each motion on the shovel. This requires three direct-current generators—hoist, swing, and crowd—and an exciter connected to the synchronous motor. The entire set is suitably mounted on the shovel. A typical set is shown in Fig. 3.

Fig. 1. 300-ton Electrically operated Shovel Loading Cars

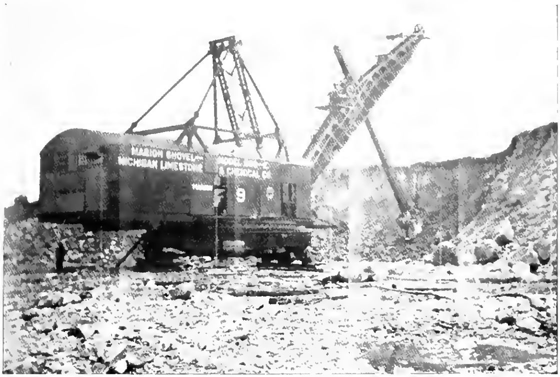

Fig. 2. Electrically-operated Shovel Taking 6 Cu. Yd. Mouthful

It should be noted that the size of the synchronous motor varies from 435 kv-a. on the largest shovels to 100 kv-a. on some of [illegible] of synchronous [illegible] maintain approximately [illegible] on the system.

[illegible] mitting the high-[illegible] shovel, which is of neces-[illegible] unique and deserves [illegible]. A specially constructed [illegible] armored cable, 500 [illegible] used. A cable reel with [illegible] is suspended beneath [illegible]. On revolving shovels, additional [illegible] and brushes provide for trans-[illegible] current from the stationary to the revolving part of the shovel. As the shovel moves away from the base of supply, which is usually the transformer station that taps the high-voltage transmission lines, the cable is unreeled; and as the shovel moves back, the cable is reeled up again. This gives a radius of operation equal to the length of the cable, or a maximum span of nearly half a mile.

For very small size shovels it is advisable to use a squirrel-cage type induction motor for driving the generator, and only one generator is used for supplying power to all of the direct-current motors. These induction motors are wound so that their primary windings can be connected for either 220 or 440 volts, for the shovels often move from one section of the country to another where the power available is of another voltage.

Another type of small shovel is the friction electric. This type depends on friction clutches for the transmission and control of the power. A small squirrel-cage motor, usually about 50 h.p., is sufficient to furnish the initial power.

A typical power input curve for a large size electric shovel, with synchronous motor-generator set and individual differential-wound generators for the various motions, is shown in Fig. 4.

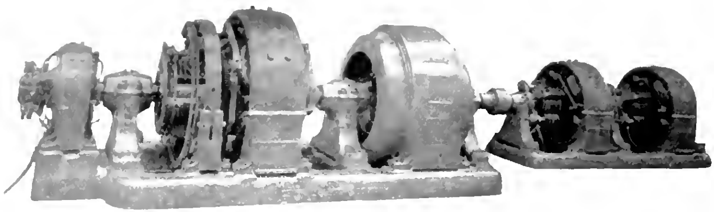

Fig. 3. Four-unit Motor-generator Set, Consisting of a Synchronous Motor, Exciter, and Three Direct-current Generators
The latter individually supply the operating motors with power

Tests on a 300-ton coal stripping shovel indicate an average power consumption per eight-hour day of 1050 kw-hr. with:

Minimum 15-minute demand........262 kw.
Maximum 15-minute demand........307 kw.
Average 15-minute demand........279 kw.

This power consumption indicates a low operating time, probably due to delays while the shovel was waiting for trains, and should be approximately 1300 kw-hr. per eight-hour shift based on 70 per cent actual working time. The instantaneous peak loads may vary from 500 to 600 kw., although they have no effect on the power bill, as power is usually purchased on a 15-minute demand basis.

TABLE I

Size Dipper Cu. Yd.	Cycles per Minute		Yardage	Motor Capacity H.P.	Average Demand Kw.	Kilowatt-Hours	
	Maximum	Average				Per Yd.	Per Shift
3/4	6	3 1/2	600	73.	30	0.25	150
1 1/2	5	3	1100	83.	35	0.25	275
2	4	2 3/4	1300	139.5	60	0.25	325
2 1/2	3 1/2	2 1/2	1500	149.5	68	0.25	375
3 1/4	3 1/2	2 1/4	1800	217.	90	0.275	495
4	3	2	2000	236.	100	0.27	540
5	3	2	2500	296.	120	0.27	675
6	3	2	3000	296.	120	0.23	690

The power consumption on the smaller revolving and railway type shovels will vary from 150 to 900 kw-hr. per ten-hour shift depending on the size of the shovel and the nature of the work. Table I presents data based on the dipper being three-quarters full of material on the average and the shovel working 55 per cent of the time on a ten-hour shift. The kilowatt-hour consumption is based on direct-current series-motor equipment and automatic contactor control without a motor-generator set.

Although the instantaneous power peaks may run rather high on any one shovel, when compared to the average demand, it should be remembered that a number of shovels will seldom, if ever, have their peaks all occur at the same time. This diversity tends to stabilize the total load, and is also a reason account of the scarcity of water. This is especially true in cold weather when pipe lines tend to freeze. It is the usual practice to shut down steam shovels during several months of the year when the extreme cold weather makes operation practically impossible. The electric shovel can operate throughout the year. The operating expense, including labor, depreciation, and repairs, is usually considerably less for the electric than for the steam shovel. This fact, coupled with the increased production, results in a consistently lower cost per cubic yard of material moved for the electric shovel.

In some cases where electric shovels have been decided on because of their numerous advantages, there will be a question as to where to obtain power for their operation. This condition will arise only on large projects

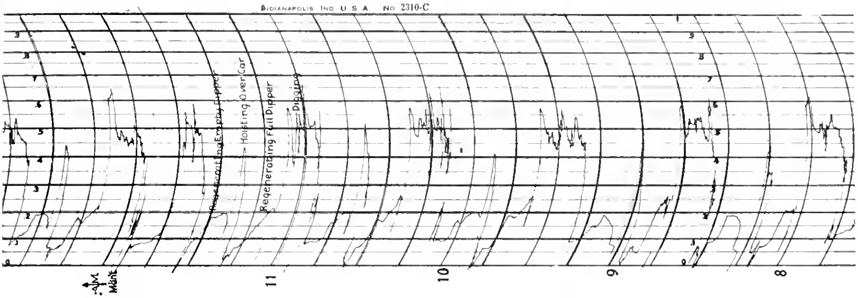

Fig. 4. Kilowatt Input to Shovel. Full scale equals 600 kilowatts. Interval between curved lines 15 seconds

for the desirability of electrifying all the shovels in a given section, for example, in an iron mine or a limestone quarry where there may be half a dozen shovels in operation. If mine operators have experience with the successful operation of shovels, there will be a tendency to electrify the entire mine, which in many cases will include an extensive haulage system.

It has been demonstrated that the electric machine has many advantages over the steam. On account of smoothness of operation and freedom from shutdowns for repairs, it is possible to move a greater amount of material in the same time. The number of men required for operating the electric shovel is usually two or three less than for the same size steam shovel. The entire machine can be kept much cleaner and neater, which means increased efficiency. In many localities the steam shovel is at a disadvantage on which are in a comparatively remote location.

On account of the potential extent of the electric shovel load, it should be attractive to the power company in the locality in which it is available. The shovel installations will be found to be quite well grouped in certain sections, for instance, on the Mesabe range in Minnesota, in the coal fields in Southern Ohio, and in the iron mines in Chile. The installation of electric shovels in quarries in connection with cement mills should be very desirable as most of these mills are already large users of electric power and the shovels will furnish a desirable addition to the existing load.

The continuous operation of electric shovels is a desirable load feature and the amount of power involved in operating several shovels will form a considerable item of load for a power system.

Electrically Driven Centrifugal Compressors

By R. S. Sage

Power and Mining Engineering Department, General Electric Company

R. S. Sage

In this brief survey attention is called to a class of load suitable for central station service, the apparatus is briefly described and indications given as to the application and the nature of its load.

Since its introduction commercially about 12 years ago, the centrifugal compressor or blower for handling air and other gases has grown rapidly in popularity, as is attested by the numerous installations in many industrial plants and public service companies.

This type of machinery, developing its pressure by centrifugal force and handling a material many times lighter than water, is essentially of high speed and in its simplest form is driven by a high-speed direct-coupled prime mover.

Its present-day wide use and broad field of application are attributable to its many advantages, when properly applied, over other types for similar service. In the centrifugal machine there is attained an even, continuous delivery of air or gas, as contrasted with a pulsating flow from the reciprocating or positive-pressure types. Such a characteristic is of great value in certain instances where an unsteady blast has a detrimental effect on the process.

Its practically constant pressure characteristic over its working range is extremely desirable in many applications. The high efficiency at which the centrifugal compressor operates is due to the employment of "conversion vanes" which change to useful pressure head much of the energy which exists as velocity head after the fluid leaves the tips of the impellers. Fan-type blowers do not have this feature and consequently require more power for equal useful work done. At constant speed the power to operate the centrifugal compressor falls off appreciably as the output is reduced; and it delivers automatically the exact volume demanded, whereas machines of the positive pressure type consume the same power at all loads, it being necessary (to meet the demands of the system) to by-pass the gas from the discharge side to the intake, or to waste it through a relief valve in the discharge piping. The centrifugal machine does not build up dangerous pressures when the discharge is completely closed, and so does not require relief valves to protect the system. Having no internal valves, the centrifugal machine is free from troubles on their account, the necessity of adjustment and repair is eliminated, and the reliability of the unit is increased.

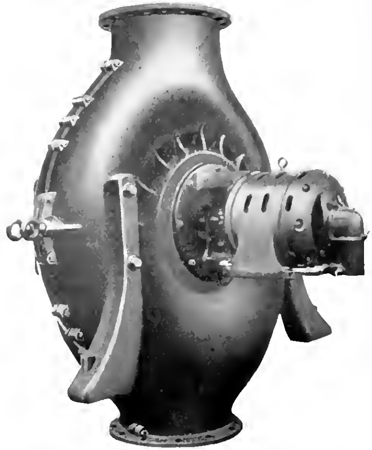

Fig. 1. Single-stage Centrifugal Air Compressor rated 10,000 cu. ft. per min. at 1.25-lb. per sq. in. discharge pressure, driven by a 2-pole, 75-h.p., 3600-r.p.m. induction motor

The simplicity of its construction renders its operation easy, and its maintenance and up-keep expenses are kept at a low figure. The compressor, with its driver, forms a unit which occupies but a fraction of the floor space of other types, and the cost of foundations is proportionately lower. Although the first cost of the centrifugal machine may be higher in some instances, it usually is justified by reason of its lower power consumption and operating and maintenance charges.

The driver employed with the centrifugal compressor may be either a motor or a steam

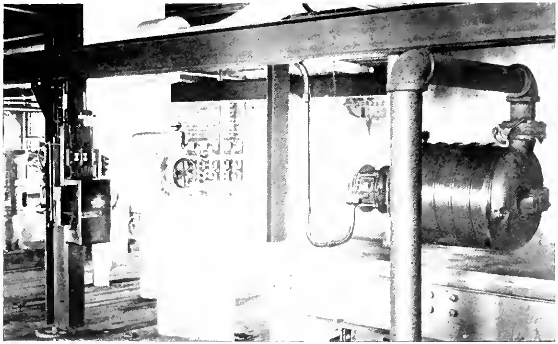

Fig. 2. Miniature Multi stage Air Compressor for 250 cu. ft. per min. at 3.25-lb discharge pressure, installed in an artificial ice plant for agitating the water to prevent formation of snow centers in the ice cake. The driver is a 6 h.p., 3 phase induction motor

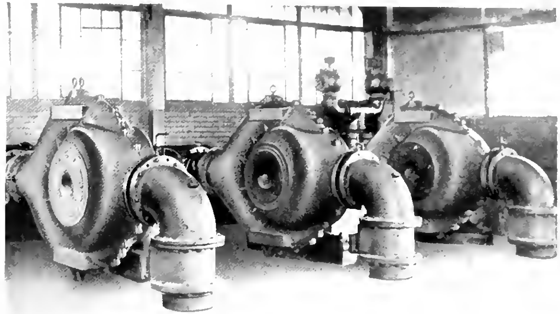

Fig. 3. Three 4200 Cu. Ft. Per Min. 2.0-lb. Air Compressor Sets, each driven by a 50-h.p., 3600-r.p.m. induction motor, used for supplying air for annealing and forge furnaces in an automobile plant

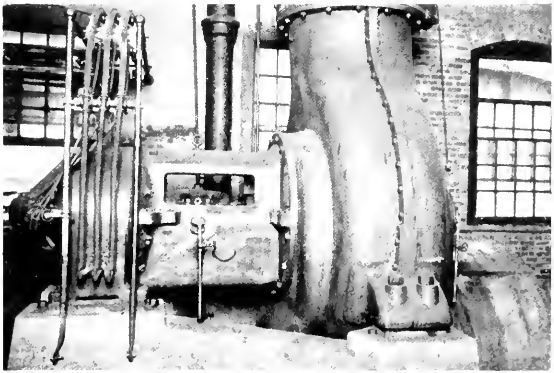

Fig. 4. Centrifugal Compressor supplying 21,000 cu. ft. per min. of inlet air at 1.50 lb. per sq. in. for a water-gas generator

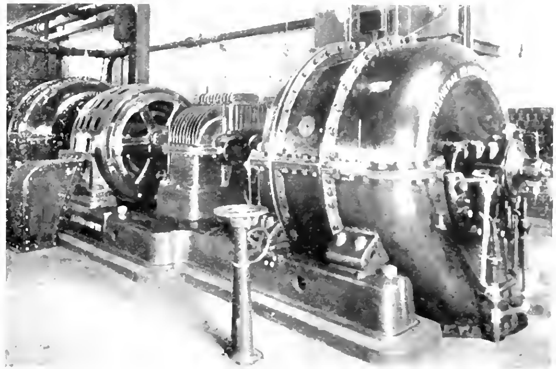

Fig. 5. Motor-driven Coke oven Gas Booster Set of 24,000 Cu. Ft. Per Min. Capacity at an Equivalent Air Pressure of 13.9 Lb. Per Sq. Inch. The compressor runs at 4150 r.p.m. and is driven by a 750-h.p., 750-r.p.m. induction motor through a step up gear unit. Constant pressure at the inlet is obtained by automatically varying the motor speed through a liquid slip regulator

[illegible] further [illegible] quite extensively used and [illegible] advantage in many applications [illegible] for gas handling apparatus requir[illegible] regulation of inlet or dischar[illegible] within extremely close limit[illegible]ermore, it generally is impractic[illegible] motors of the capacities often r[illegible] at speeds suitable for direct [illegible] compressor, without the use of intervening gearing.

Centrifugal compressors may be classified as follows:

(a) Miniature, multi-stage, motor-driven units.

(b) Standard, single-stage, direct-current and induction-motor and turbine-driven units.

(c) Multi-stage, gas and air, motor and turbine-driven units.

(d) Multi-stage, blast-furnace, turbine-driven units.

Compressors of the first class are of small capacity, namely, 250 to 350 cu. ft. per minute, for pressures ranging from 1 to 3.25 lb. per sq. in., are self-contained and motor driven from direct-current or alternating-current circuits. The motor capacities range from 3 to 8.5-h.p. output.

These small units have been applied for the most part for:

(a) Aerating water in the manufacture of artificial ice

(b) Supplying air for certain chemical processes in chemical and dye works

(c) Supplying air to small heat treating and other furnaces and to blow torches

(d) Supplying ventilating air to electrical apparatus.

Fig. 2 is a view of an installation of one of these compressors in an artificial ice plant.

Compressors of the second class mentioned comprise a standard line of single-stage motor and turbine-driven machines with ratings varying from 800 to 13,500 cu. ft. per min. for $\frac{3}{4}$-lb. to $3\frac{1}{4}$-lb. pressure. The driver capacities range from 5 to 90 h.p. continuous.

By far the greatest number of installations are made from this class of machines, and the standard line has been extended to include single-stage units up to 25,000 cu. ft. per min. at 5.0-lb. pressure. At this rating an air machine would require approximately 725 h.p., which would best be supplied by a geared induction motor or by a direct-connected high-speed synchronous motor.

Fig. 1 shows a single-stage machine of this type driven by a 75-h.p. 3600-r.p.m. induction motor. The compressor openings may be arranged horizontally opposite instead of vertically as shown.

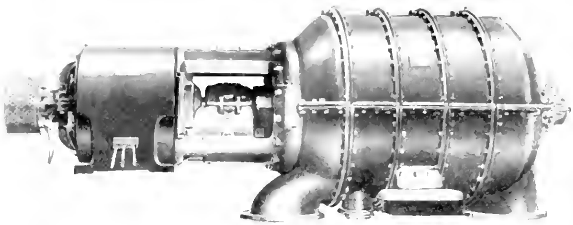

Fig. 6 Factory View of a 4-stage Centrifugal Gas Booster with Direct-connected 400-h.p., 6300-r.p.m., Slip ring Induction Motor with Overhung Collectors. This compressor handles 8340 cu. ft. of inlet gas per minute and develops an equivalent air pressure of 22.0-lb. per sq. in. gauge

Among the applications for which compressors of this class are suitable are the following:

1. *As Air Compressors*

(1) Foundry cupola blowing

(2) Oil, gas, and powdered coal burning furnaces for

(a) Forging

(b) Tempering

(c) Annealing

(3) Reverberatory furnaces in metallurgical processes

(4) Water-gas generator blowing

(5) Pneumatic conveying systems for ashes, coke breeze, cement, coal, sawdust, starch, parcel and cash carriers, etc.

(6) Liquid agitation as

(a) Water agitation in ice manufacture, sewage disposal, etc.

   (b) Yeast agitation
   (c) Callow flotation process of copper concentration
(7) Copper-blast-furnace blowing
(8) Vacuum systems of cleaning
(9) Scavenging cylinders of Diesel engines.

II. *For Gas Handling*
(1) Exhausters and boosters for
   (a) Coke-oven gas
   (b) Illuminating gas
   (c) Producer gas
   (d) CO_2, SO_2, etc.

Figs. 3 and 4 illustrate typical motor-driven single-stage compressor installations for some of the applications outlined.

While the third class of compressors includes for the most part turbine-driven gas exhausters and gas boosters of the multi-stage type, in some instances it has been found desirable to use motors for this service.

In Figs. 5 and 6 are shown examples of coupled and geared motor-driven gas compressors of the multi-stage type.

In the last division there are included principally those compressors used in blowing blast furnaces. Turbine drive is employed in every instance and requires up to 7000 h.p. maximum. There is seldom any occasion to consider electric drive for these blowers, as the greatest economy is obtained by steam turbines using steam generated by boilers fired by gas from the blast furnaces.

Electric drive for compressors used in steel and copper converter blowing has been considered quite practicable, the air being used at a nearly constant pressure and requiring no especial governing devices. As the capacities involved are comparable with those for blast-furnace blowers, gearing is necessary and slip-ring induction motors are used to permit reducing the speed when the converter vessel is turned down for pouring or recharging.

For the most part the load afforded by the centrifugal compressor is uniform and continuous over the regular working hours in the plants where used, and in many instances the load is on a day-and-night basis. For some processes the operation is of an intermittent character or follows a continually repeated cycle. Cupola service is for the greater part an example of intermittent operation, the blowing usually being done during only a portion of the day, the time varying of course with each individual plant but ordinarily ranging from two to five hours. In the case of the continuous foundry the blower load is of course also on a continuous basis.

In the manufacture of water gas, air is forced into the generator for a period of about three minutes and shut off for four minutes, this cycle being repeated continuously. When not blowing, i.e., when the outlet is closed, the driving motor develops about 50 per cent of its full output.

Most of the applications require but infrequent starting, and as the compressors usually start under light load, the demands on the power supply are held within reasonable limits. As the driving motors usually operate at high speeds, the power-factor is correspondingly high.

Squirrel cage induction motors are used for the most part for capacities of 200 h.p. and less, and slip-ring motors are best adapted above this limit as the starting peaks can be held to a low value and the operation of the unit at reduced speed is made possible thereby resulting in a saving of power when variable pressures are desired.

Motor Drive in the Woodworking Industry

By F. H. Penney and E. L. Bamforth
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F. H. Penney

E. L. Bamforth

THE rapid destruction of materials during the world war provided a tremendous stimulus for the woodworking industry which includes the manufacture of all wooden products from the raw material supplied by the lumber mills. Unfortunately, the growth while large and rapid was not always along the way of the latest development. The extreme urgency of the situation demanded action, and other considerations however desirable and feasible were often put aside for the time being if they incurred delay. The abnormal requirements necessitated prompt efforts to keep materials moving. In too many cases, the lack of up-to-date machinery and motors available at once made itself evident, and accordingly materials at hand were utilized to the best advantage. Therefore, while the woodworking industry as a whole developed remarkably, it is to be regretted that so much work was done which was not along the lines dictated by the best practice.

Many builders of woodworking machinery are at the present time engaged in improving their products. It is no longer disputed that the directly applied motor is more efficient and that it pays for itself in the long run, since it eliminates belts, shafts, countershafts, gears, etc., with their upkeep; and applies power directly to the saw or cutter spindle where it is actually needed. Most of the requirements of wood working machinery, except for the feed motors, demand high speed, a pertinent fact since it permits the use of motors of small dimensions for a given horse power and, consequently, comparatively cheap motors. This is especially fortunate since the multiplicity of motors required in most cases would otherwise prohibit the use of separate units on each spindle. To illustrate, one modern machine utilizes nine individually applied motors and a great number of wood working machines require from three to seven individual units.

The fact that close-up views of individual machines are shown in this article rather than general interior views of woodworking factories will undoubtedly be the subject of comment. However, after going over the situation carefully, it was decided that a better idea of the applications would be ob-

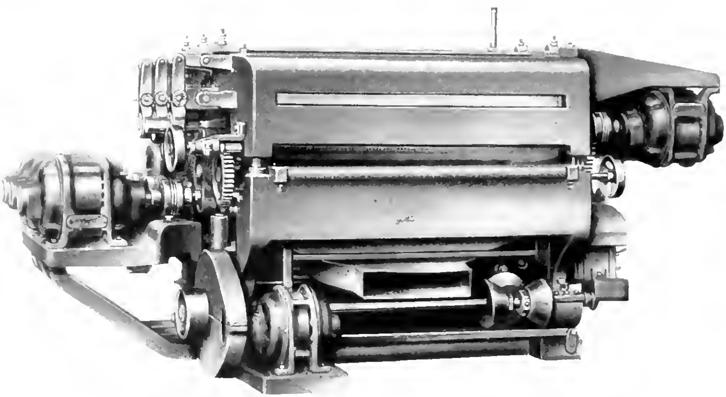


Fig. 1. Six-drum Sander with Motors Coupled Directly to Drums, Feed Motor Below

tained from the illustrations of representative machines used in the average plant rather than a general view of some particular factory, and selections were made accordingly.

Fig. 1 illustrates a type of machine, a six-drum sander, which occupies a prominent place in many woodworking factories. This machine requires six motors of the constant-speed type, one coupled to each sanding drum, while a seventh motor provides power for the feed. This type of drive eliminates all belts, gears, etc. The material to be worked can be moved up adjacent to the machine and thus a minimum handling is involved, and the machine is kept provided with work at a rate insuring continuous production.

Fig. 2 shows another type of woodworking machine widely employed, some form of which exists in a large number of the woodworking shops of the country. The older forms were driven by one motor, power being transmitted to the machine by a belt and thence to the various spindles by other belts. Much difficulty in securing uniform speed was encountered; the belts would stretch and the speed of the cutters or knives would vary instead of remaining constant, with the natural result that there was lack of uniformity in the product. Contrast this with the machine shown, each cutter having its own constant-speed motor, all of which are driven from the same source of power and consequently operate at rated speed continuously and thus produce uniform work. In addition, a continuity of service during normal as well as critical periods is secured and a freedom from annoying shutdowns provided.

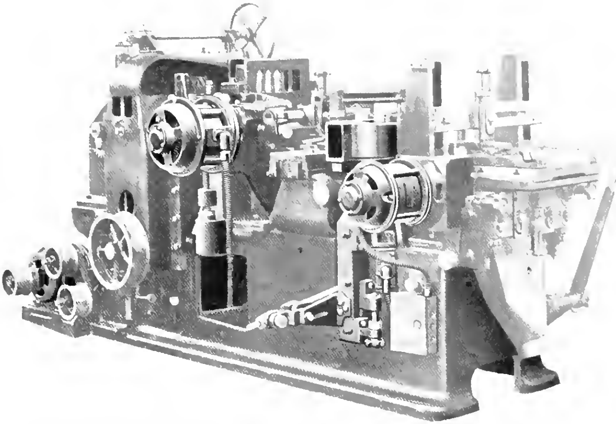


Fig. 2. Side Moulding Machine Driven by Five Squirrel Cage Motors, Two Horizontal and Two Vertical, All Directly Connected to Spindles. Feed Motor is Shown at Left Near the Floor

In Fig. 3 is a machine employing three motors, two of which, those on the horizontal spindles, are applied somewhat differently than those in Fig. 2. These two motors are of the built-in type and the small dimensions of this type of motor render feasible its application in many places heretofore considered impossible. This point is brought out by noting the proximity of the two horizontal motors. The outside shell or casing together with the bearings are built by the machine tool manufacturer, and as may be seen the outside of the frame is constructed as a part of the machine on which it is placed.

On the right of Fig. 3 may be seen the control apparatus necessary for starting and stopping the motors which are, in the cases mentioned, thrown directly across the line by means of a manually operated switch. Magnetic control can be arranged to provide sequence starting, so that it is only necessary to push a button starting the first motor, the others starting automatically. In this case provision is usually made to cut out any motor in case of need without affecting the other units.

In providing sequence starting, excessive starting currents are avoided as the first motor is up to speed before the second is connected to the line. This arrangement eliminate [illegible] of the power companies, su[illegible] motors of small or intermediat[illegible] do not seriously disturb the [illegible] starting in sequence as would be [illegible] en a number are started simu[illegible]

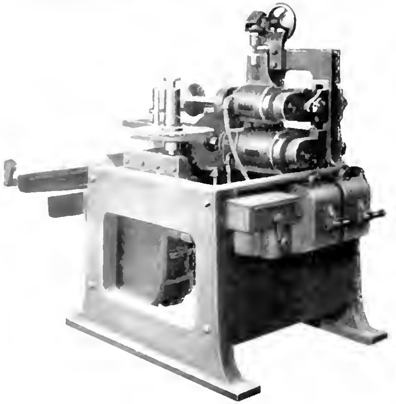


Fig. 3. Saw Tenoner with Directly Applied Motors for Driving the Three Saw Spindles. Manually controlled switches are mounted on the side of the machine

Another feature of the power demands of the woodworking industry is the ultra high speed required by some classes of work. In cases of this sort a motor generator or rather a frequency changer set is employed to provide power at frequencies above those of the commercial circuit. Shapers, high-speed drills, and carving machines are examples of apparatus requiring power at frequencies varying in range from 80 to 180 cycles. Speeds ranging from 4800 to 10,800 r.p.m. are thus obtained with essentially the same motor as used on commercial circuits.

Fig. 4 shows a shaper of the old type employing a single motor belted to both spindles, this being an adaptation from line shaft drive, the motor supplanting belts from the ceiling but still retaining the troublesome quarter-turn belts and wasting a large amount of valuable floor space.

Fig. 5 illustrates a modern type shaper, each spindle of which is driven by a built-in motor running ordinarily at 7200 r.p.m. The contrast is so great that comment is unnecessary.

An induction frequency changer set supplies the necessary 120-cycle power. This set is extremely simple and consists of a standard squirrel-cage induction motor and the driven unit, the induction frequency changer. The frame of the frequency changer is the same as that of a standard slip-ring type induction motor. In practice, power is supplied to the stator of the frequency changer by the commercial circuit and the transformed three-phase power is taken off the slip rings, the frequency of which depends on the revolutions per minute of the rotor, the number of poles for which the stator is wound, and the frequency of the supply circuit.

It is probable that in the days when steam engines were universally used to drive line shafts in industrial plants, the waste material was best disposed of as fuel for the furnaces. Later as electric drive came into use, the natural step was to belt the steam engine to an electric generator and simply isolate the power plant. The next step in development came as the ability of the central station to supply power for industrial plants became evident.

Woodworking shops were, by virtue of their waste product, naturally reluctant to change over since considerable of their waste was used to produce power and eliminate the buying of outside fuel. Therefore it became necessary for the central station to demonstrate the advantages of outside service.

One of these is the ability to start the various individual machines at any time independently of regular working hours, such as overtime, as power from the station is always available. Many plants having their own generating equipment, to avoid the possibility of shutdowns in emergency, paid for stand-by service from the central station, thus recognizing that the power supply from the central station was dependable. This stand-by service is expensive, however, and oft times a dead loss as it may not be used.

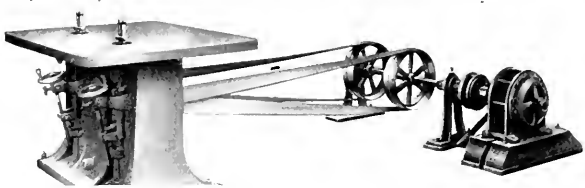


Fig. 4. Double Spindle Shaper Driven by a Single Motor Belted to the Spindles

One of the problems which is presented to the power salesman is the disposition of the waste product, which owing to its nature is often utilized to provide steam power to help in the operation of the plant. The manager of the wood working plant usually does see many advantages to be gained by the purchase of power but he is up against the problem of disposing of the waste. This may reach even 40 per cent of the lumber used, varying greatly with the material manufactured and the quality of the raw stock available.

In a certain box factory the solution was found to be in segregating the waste products such as the sawdust, shavings, and the few ends or blocks. This was accomplished by suitably arranging the exhaust system. Here it so happened that there were but few blocks and ends left as the box factory used up practically all such material. The sawdust and ends were burned to produce steam for the dry kilns and the shavings were baled. It was demonstrated that the advantages obtained in handling the shavings thus disposed of more than offset the cost of baling in that the shavings could satisfactorily be handled and sold in this form. In this particular case, disposal was easy as it was found that another firm in a remote part of the city was purchasing and paying freight on shavings for packing. Baled shavings and a motor truck gave the answer since the price including delivery yielded a profit at a lower figure than the material could be brought in by rail.

Another case occurred where the waste, instead of being largely shavings, was made up of ends and strips. Following the usual practice of many concerns in this line of work, this material was burned. The first occasional calls for fuel came from peddlers who retailed the material to bakers and householders. This demand developed the idea of selling the whole of this product and utilizing coal to provide steam for heating and the dry kilns. Experience demonstrated that this scheme was feasible. Therefore a contract was made with a local dealer providing for complete disposition. The dealer found no difficulty in selling the material as it was always dry seasoned wood. Under this system it was found that power could be purchased and coal utilized to the mutual advantage of both the central station and the woodworking concern.

Naturally the fire risks in woodworking establishments are higher than in most other industrial plants. The very nature of the product and the waste resulting from working such material all contribute to the risk. Here is where the simple reliable squirrel-cage induction motor is especially welcome and adaptable. There are no commutators, no sparks from brushes to set fire to the most inflammable material. While the induction motor is not ideal from the central station point of view, owing to the low power-factor,

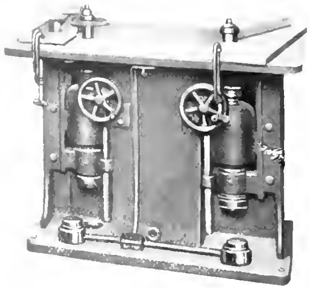
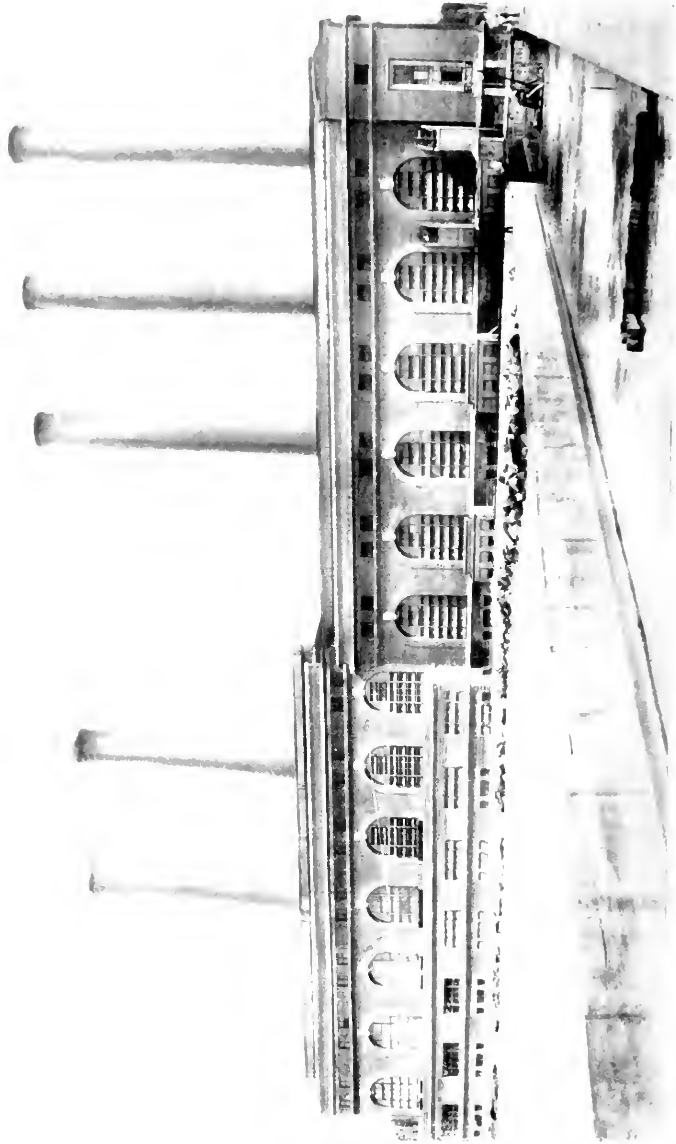


Fig. 5. Double Spindle Shaper, Each Cutter Driven by a High Speed Built-in Motor. Push button control panel concealed in base

yet if the motors have been judiciously selected from the data now available, it will be possible to work each motor up to a point where its power-factor will be sufficiently high to make the load an attractive one. With modern control the ease of operation renders feasible the shutting down of a machine until work is provided. It may then be started again with little loss of time or effort on the part of the operator, and with consequent saving in power during the idle period. This is especially true where a number of motors are used on one machine. Individual motors may be cut out and thus neither the power-factor nor efficiency of the others is affected as would be the case where one motor drives a group of spindles.

The load-factor in a woodworking plant varies through a wide range so that the connected load with no other data is of but little value. In the small shop where the work for a machine varies, the load-factor may be only 35 per cent, while in the large well-planned and equipped factory doing duplicate work, this factor may reach 85 per cent and for short periods a little higher. Only a careful study of the working conditions renders it possible accurately to foretell what the load-factor will be.

It is appreciated that figures showing improved efficiency or savings made are omitted as it is felt that such figures while interesting have but little bearing on any other plant where a different set of conditions prevail.



Lake Shore Station, Cleveland Electric Illuminating Company. Probably the Largest Central Station in Existence in which Ten Turbine-generators with a Total Capacity of 228,000 kw. are Installed

The Paper Industry

By H. W. Rogers and E. E. Warner
Power and Mining Engineering Department, General Electric Company

H. W. Rogers

Paper, like the telephone and the major part of our modern conveniences, has become so common that it is accepted without any thought as to what lies back of its production. It has become so much a part of our daily existence that it borders on the ridiculous to ask even the smallest child to define it.

The dictionary says it is a thin flexible substance made of various materials such as linen, straw, etc., but makes no mention of its process of manufacture or its importance as an industry. To separate it from our civilization would be a calamity and to attempt to explain how far it has been responsible for our present state of advancement would be a difficult problem. Its most important field is probably in the dissemination of knowledge, although it is used for various other purposes in all industries. It is surprising, therefore, that so few of the millions of individuals who daily use paper should give any thought to its constituents, where it comes from, how it is made, and where it goes after it has served its usefulness; and yet the paper making industry stands well to the front in matter of importance and size, and is a large factor in our national life.

It is not possible to obtain statistics for the past year, but the Bureau of Census report for 1914 gives some very interesting facts about this great industry.

In primary horse-power requirements, it probably ranks about fourth in our numerous industries, with 1,621,154 horse power in 1914. This has been increased enormously during the last few years, but accurate statistics are not available at this time. Of this total power about 500,000 horse power is electric and the balance steam engines, waterwheels, etc.

The fuel used is largely coal, as is shown in Table I.

The labor employed in 1914 was 95,516 persons and capital invested, $534,624,000. The value of the product for that year was $332,147,175, of which $118,965,889 was added in the process of manufacture. In 1918 there were 821 pulp and paper mills in the United States producing annually 5,658,000 tons of paper and board valued at $780,000,000. During this period the pulp wood consumption was 5,250,794 cords, about 50 per cent of which was spruce.

E. E. Warner

Paper is not all alike, except that it contains cellulose, and may be briefly divided into classes as shown in Table II.

Where wood pulp is used it has been confined almost entirely to spruce, hemlock, fir, poplar and pine, although other woods have been used experimentally with success. Sugar cane and bamboo contain cellulose in sufficient quantities for making paper, but the former has not been used in the art because it is difficult to maintain a supply sufficient to keep a mill in operation continuously, while the use of the latter is just being developed.

TABLE I

Anthracite	830,500	short tons
Bituminous	6,268,853	short tons
Coke	15,455	short tons
	7,114,808	short tons
Oil	635,329	barrels
Gas	2,260,562	(thousand) feet

The bulk of paper is manufactured from wood pulp and therefore lumbering becomes a part of the paper industry, and since our daily papers use such enormous quantities of newsprint, all three industries are very closely related.

Space does not permit of differentiating between the various kinds of paper and the difference in manufacturing processes, and since the same machines are used in practically all instances the newsprint will be taken as an illustration. The flow sheet shown in Fig. 1 not only gives the process of ma[illegible]ufa[illegible] [illegible] the various machines, used in th[illegible] [illegible] while the power chart shown [illegible] III approximates the power requir[illegible] [illegible] output closely enough for [illegible]

[illegible] industry uses such a wide [illegible] or presents so many [illegible] in power application [illegible] paper industry, and probably no other industry has tolerated the use of the old type of mechanical drives so long with its line shafts, counter-shafts, pulleys, belts, gears, clutch, etc. Its efficiency is low, its maintenance is high, and it is difficult to explain why this condition has existed so long. However, the old mechanical drive is rapidly being replaced by the more modern and more efficient electric drive. This change may be due to competition or it may be due to the demand for increased production. In either case the outcome is the same and the result is a much more efficient and flexible drive which permits of an analysis of production costs not heretofore possible.

A few of these machines, such as supercalenders and platers, are not found in a news mill but are common to other mills, and with the exception of the paper machine and possibly the rewinders (which require direct-current motors) alternating-current induction motors may be used throughout.

During recent years, however, the tendency has been towards synchronous motors on grinders and Jordans, as the load is steady and offers an excellent opportunity for power-factor correction.

As shown in Table III, the grinders constitute about 75 per cent of the entire load in a paper mill and where small units were in vogue years ago, a 300, 400 or 500 horse-power induction motor being used to drive a single stone, it is now the practice to use larger units of 1000, 1500, or 2000 horse power to drive a number of stones on the same shaft, and in not a few instances motors of 2400 and even 2800 horse power have been used. The advantage in power factor and efficiency is all favorable to the larger units, as only synchronous motors are being used.

The load on grinders is subject to wide variations due to refilling the pockets, but this variation may easily be overcome and a constant load maintained by using a regulator which governs the water pressure

TABLE II

MATERIAL	Wood	Ground wood Chemical Pulp		News print Book paper Wrapping paper Tissue Glassine Wall paper Lithographic
	Rag	Linen Cotton		Writing papers Book papers (high grade) Parchment Stocks, bonds, legal documents Tissue
	Straw	Barley Oat Wheat Rye	Straw board Pasteboard	
	Hemp and Jute	Wrapping papers		
	Low grade rags Waste paper	Roofing paper		
	Bamboo	Book Writing papers		
	Bagasse	Crushed Sugar Cane	Glassine and Parchment	Experimental
	Esparto	Grass	Art Antique Book Lithographic Printing	

used in the grinder cylinders; and it is also possible to maintain a practically constant mill load by this same means.

The paper machine is, without doubt, the most important machine with which we have to deal, as the entire production of paper is dependent upon it; and yet it has been one of the last machines on which any great changes or improvements have been made in the drive.

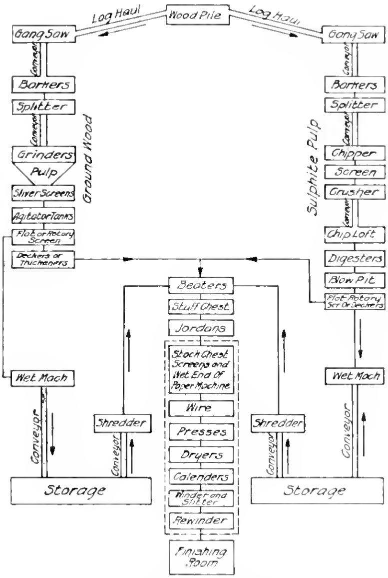


Fig. 1. Flow Chart Showing the Processes and Machines Employed in Paper Manufacture

The quality of the product depends very largely upon the type of drive selected and its proper application with respect to the machine. Speed regulation, flexibility of control, and uninterrupted service are all important factors and must be given careful consideration.

For this reason it is desirable to have the paper machine and its drive a unit in itself, independent of the rest of the mill.

In the process of making paper, the stock comes onto the machine about 99 per cent water, and although a large part of this is removed by the suction and the presses, there still remains 40 to 50 per cent of moisture which must be taken out of the paper while it is passing over the dryers. The heat for accomplishing this drying is supplied usually by exhaust steam from the engine which drives the paper machine, supplemented occasionally by live steam. The

TABLE III

POWER DATA FOR A 100-TON NEWS MILL

Product consisting of 80 tons ground wood and 20 tons chemical pulp.

DEPARTMENT	HORSE POWER
Ground Wood	
Wood Room	111
Grinder Room	7016
Sulphite	
Wood Room	125
Screens, Pumps, etc.	171
Machine Room	1844
Finishing Room	63
Machine Shop	40
	9370

Boiler capacity required for heat, cooking and drying . . . . 1350 h.p.

TABLE IV

MACHINES USED IN THE INDUSTRY

GROUND WOOD	CHEMICAL PULP
Log Hauls	Log Hauls
Saws	Saws
Conveyors	Conveyors
Barkers { Drum, Disc }	Chippers
Splitters	Digestors
Grinders { Pocket, Magazine }	Pumps { Centrifugal, Plunger }
Screens	Screens
Pumps { Centrifugal, Plunger }	Agitators
Agitators	Wet Machines

Beaters	Paper Machines
Jordans	Winders
Agitators	Cutters
Screens	Supercalenders
Pumps	Platers

am[illegible] [illegible]ured varies somewhat but [illegible] pounds for each pound of paper [illegible] ranges in pressure from 0 gauge [illegible] pounds gauge and in some few ca[illegible] twenty pounds gauge.

Th[illegible] uses for steam in the mill, [illegible] and heating, but 11 boiler [illegible] ton of paper will ordinarily [illegible] care of all requirements.

The necessity for steam in the process of manufacture prevents a complete electrification unless live steam is used; consequently the prime mover for the paper machine must be either an engine driven generator or a turbo-generator set with preferably a little less exhaust steam at the proper drying pressure than is actually required, live steam being used to make up the deficiency rather than have too much steam and allow it to go to waste.

In a few cases synchronous motor-generator sets have been used as prime movers and live steam used entirely for drying.

Under normal operating conditions a paper mill runs twenty-four hours a day six days a week with very few holidays, so that it may be considered as a continuous load. The average load with properly applied motors will be about 80 per cent of the connected horse power and the maximum demand very little above this figure.

Enormous strides have been made in the electrification of this industry during recent years, but as the statistics indicate, we have only scratched the surface as yet. To be sure there is a large amount of water power utilized in the industry, but it is not always used efficiently and there are hundreds of mills in this country still to be electrified to say nothing of the new mills being developed.

Electric Pumping

By L. F. Adams and R. A. Jones
Power and Mining Engineering Department, General Electric Company


L. F. Adams

THE invention of the steam engine approximately 150 years ago, augmented by the commercial development of electricity approximately 50 years ago, has resulted in a demand for power driven pumps that has been continuously increasing to the extent that today more power is used for driving pumps than for any other single type of machine in existence.

There is scarcely a manufacturing process or a modern domestic convenience which does not depend at least partially upon pump equipment. In the extreme west there are millions of acres of land which owe their productivity to this machine alone; while in the middle west, large sections which were formerly vast swamps are now drained and made into valuable farming districts. In the mining industry the problem of discharging water equals that of discharging the ore, and in some coal mines two tons of water are elevated for every ton of coal. Then, too, there are paper mills, sugar mills, chemical plants, and numerous others which depend upon pumping equipment for the flow of the product through the different processes. Also there are dry docks for ship repairing, humidity pumping systems in the textile industry, hydraulic jacks, rams, elevators, etc., and municipal water systems which provide fresh water supply, sewage disposal, and fire protection, all of which are seldom thought of by the general public. The municipal plant is one of the largest pumping power users. Most cities require from 100 to 200 gal. per capita per day.


R. A. Jones

The fulfilment of this enormous demand is made possible through the capabilities of electricity, since with our present extensive transmission systems economical power is obtainable wherever it is needed. This distribution characteristic coupled with the reliability, cleanliness, lack of noise, ease of installation, and simplicity of control would in itself make electric drive desirable. However, the additional high economy has caused the electric motor to be universally adopted for pump drive, and in many cases has actually replaced steam engines.

Numerous comparative tests made during the last few years show that with few excep-

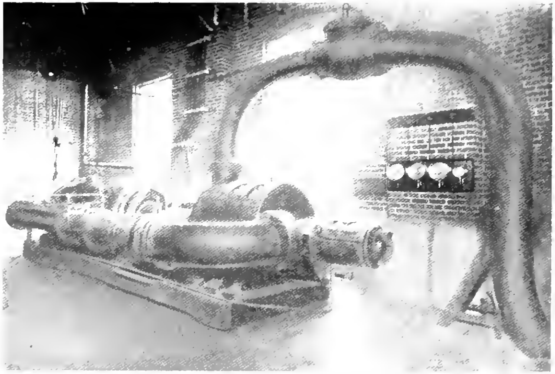


Fig 1 1300-h.p., 1200-r p.m., 2200-volt Wound rotor Induction Motor Direct Connected to Double-suction Impeller Pump of 6,000,000 Gal. Capacity per 24 Hr Against a Head of 875 Ft

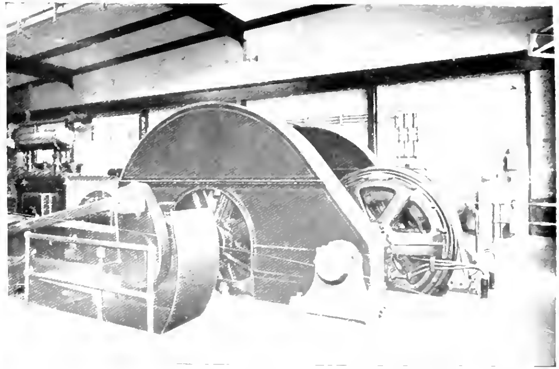


Fig 2. 800-h p , 360-r.p.m , 2080-volt Wound-rotor Induction Motor Geared to a Pump Originally Driven by a Steam Engine

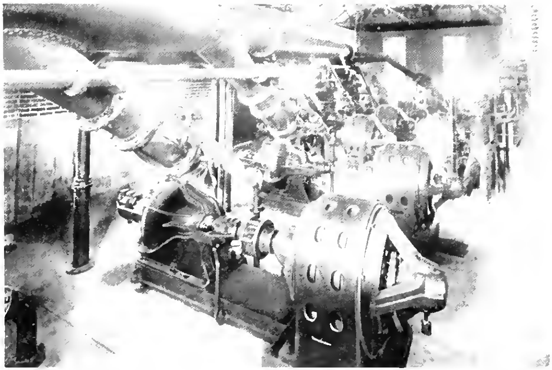


Fig 3. Several Sets of Motor-driven Centrifugal Pumps Supplying an Irrigation Project

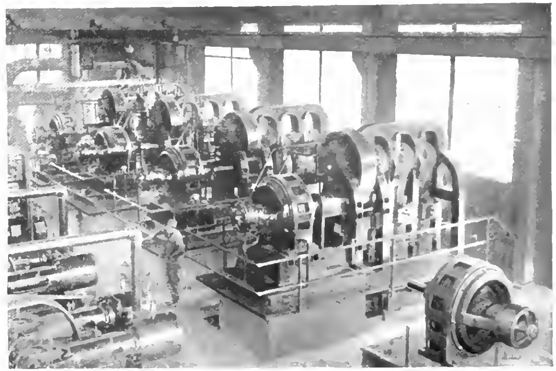


Fig. 4. Four 105-kv-a , 500 r p m , 2200 volt Synchronous Motors, with Exciters, Direct Connected to Triplex Pumps in a Copper Concentration Mill

tion electricity is superior to steam or gasoline, regardless of the size of the units.

A small town in Indiana with a population of approximately 2500, has replaced its steam equipment with two 400-gal. motor-driven centrifugal pumps and estimates the saving at approximately $2000 a year. Tests of motor-driven pumps in fourteen other towns in the same state, ranging in population from 500 to 2500, showed that their operating costs per 1000 gal. varied between $0.88 and $16.83 with an average of $4.974. Reduced to the basis of a 100-ft. head, this average becomes $3.744 per 1000 gal. 100 ft. Detail information covering operating costs for some of these towns is shown by Table I.

An interesting comparison of a motor drive and a gas-engine drive is afforded by a small town in New Jersey which has two duplicate 350 g.p.m. reciprocating pumps, one driven by a 30-h.p. motor and the other by a 30-h.p. gas engine. The motor driven pump uses an average of 17.5 kw. per hour and the gas engine 550 cu. ft. of gas per hour. At the prevailing rates of 2½ cents per kilowatt-hour and $1.15 per 1000 cu. ft. gas, the hourly costs are 44 cents for the motor and 63 cents for the engine. The motor-driven pump has the additional advantage of providing for automatic operation, starting and stopping as the water in a stand-pipe falls or rises to predetermined elevations.

Another good example of the superiority of motor drive to gas-engine drive is afforded by a town in Connecticut which has recently installed a 100-h.p. motor-driven reciprocating pump and has found the prevailing costs of the motor-driven unit for 1919 (including wages, power, oil, and repairs) to be 20 per cent less than that with a gas engine. Detailed unit costs covering this comparison, based upon 1000 gal. against a 273-ft. head are shown by Table II. The greater capacity of the motor-driven pump explains its higher cost for oil, supplies and repairs.

The feasibility of electric pumping for private homes is evidenced by data obtained from watthour meters installed in several residences equipped with pressure-tank systems for soft water supply to bath room, kitchen, and laundry. These meters revealed a maximum consumption of 0.75 kilowatt-hour and an average of 0.45 kilowatt-hour. per person per month. It is evident from this that at the prevailing rates, 1 cent per day for electric energy is sufficient to provide an abundant supply of soft water for the average city family.

Similar comparisons of operating costs covering pumping equipment in larger cities

TABLE I

DATA ON MOTOR-DRIVEN PUMPS IN THE STATE OF INDIANA COLLECTED ON INSPECTION TRIPS, 1919†

Town	Population	Total Head	Annual Pumpage Million Gal	Annual Energy Consumption Kw.-hr.	Kw.-hr. per 1000 Gal	Kw.-hr. per 1000 Gal. per 100 Ft Head	Total Annual Operating Cost Dollars	Operating Cost per 1000 Gal. Cents	Operating Cost per 1000 Gal. per 100 Ft. Head Cents
A	13,000	115	300*	383,300	1.28	1.11	14,603.58	4.86	4.23
B	10,000	484	478	1,565,000	3.28	0.68	15,174.11	3.20	0.66
C	8,700	212	422.4*	307,130	0.73	0.34	14,000	3.31	1.56
D	3,800	150	36*	52,800*	1.47	0.98	1,210.23	3.36	2.24
E	2,500	102	69.8	64,810	0.93	0.91	2,411.05	3.45	3.38
F	2,400	136	66.83	75,140	1.12	0.825	3,849.56	5.76	4.24
G	2,400	160	646.25*	129,250	0.20	0.125			
H	1,900	100	43.08	58,300*	1.35	1.35	1,494.51	3.50	3.50
I	1,600	120		98,455			6,263.60		
J	1,400	100	55.1	60,000*	1.09	1.09	1,634	2.97	2.97
K	1,400	132	18*	27,912	1.55	1.17	658.24	3.66	2.77
L	1,300	106	30*	8,230	0.27	0.25	263.30	0.88	0.83
M	1,200	148	43.12	100,000*	2.32	1.57	3,850	8.93	6.05
N	1,200	120		5,878			329.23		
O	1,100	137		5,888			333.55		
P	1,100	125	10.9*	26,740	2.45	1.96	1,835.14	16.83	13.5
Q	800	144	13*	3,770	0.29	0.29	515.20	3.96	2.75
R	600	145		13,330			805		

* Estimated

Average kw.-hr. per 1000 gal.	1.31
Average kw.-hr. per 1000 gal. per 100 ft. head	0.90
Average operating cost per 1000 gal. in cents	4.97
Average operating cost per 1000 gal. per 100 ft. head in cents	3.74

† Bulletin No. 4 Engineering Experiment Station, Purdue University.

also show electric drive to be the more economical. A city in New York State, having a population of more than 100,000, has recently investigated the desirability of electric drive and estimates that the cost of electric power for pumping at their filtration plant will be approximately $19,000 as compared with $50,000 for coal. A similar comparison made by a city in Georgia, based upon the performance of a 200-h.p. centrifugal pump unit, revealed a saving of $25 per 1,000,000 gal. by using electric drive in place of steam. When the entire plant is changed over it is estimated that a saving of $57,500 a year will be effected in fuel and labor. Comparative data covering a 2,500,000-gal. motor-driven centrifugal pump unit installed in a town in New Hampshire shows that to pump 1,000,000 gal. costs $25.90 with electricity and $28.54 with steam.

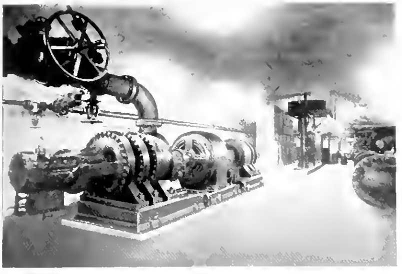


Fig. 5. 1050-h.p., 1200-r.p.m., 2200-volt Induction Motors Installed in a Pumping Station of an Iron Mine

The desirability of using synchronous motors for pump drive is illustrated by an installation in Canada, consisting of a 3500-g.p.m. centrifugal pump driven by a 325-h.p., 70 per cent power-factor synchronous motor. Statements available covering operating costs by steam for the year 1917 show a total cost per million gallons of $11.80 as compared with $10.56 with electricity in 1919. These figures include the items of coal, totalling $6.51; labor, totalling $3.74, and supplies, totalling $1.55 for the year 1917. For 1919 the figures are $4.77 for electric power, $2.23 for labor, $1.88 for supplies and in addition $1.07 for coal to carry banked fires in the old boiler plant. Coal was figured at $6.89 per ton in 1917 and $7.18 in 1919. These figures indicate a saving of from 10 to 12 per cent or $1500 per year exclusive of the corrective kilovolt amperes obtained, and also in addition to the standby service of the old steam pumps.

Another remarkable example of the superiority of electric driven pumps is shown by comparative tests made upon pumping equipmade in Minneapolis, Minn. The pump unit consists of a 30,000,000-gal. centrifugal pump driven by a slip-ring induction motor. Records maintained over a nineteen months' period show a power cost of $3.72 per 1,000,000 gal., and a labor and supply cost of $1.77, making a total of $5.19 per 1,000,000 gal. Figures available from two steam engine units having a capacity of 15,000,000 gal. each show a total cost of $6.75 per 1,000,000 gal. This cost consists of coal at $2.07 per ton or $3.01 per 1,000,000 gal., labor $3.33, lubricating oil, etc., $0.35. Comparative data covering costs for the pumping equipment of the city of St. Paul show that operation by steam during the year of 1916 costs $4.44 per 1,000,000 gal. raised one foot as compared with $3.71 for electricity during the years 1918 and 1919.

The foregoing examples taken at random show conclusively the superiority of electric over other forms of drive. Most pumps run continuously either during the entire twenty-four hours or during the working day in industrial plants. As the load is a steady one with no fluctuation, or at least very little, it is evident that motor-driven pumps are very desirable in any power system. Additional attractive features are the possibility of power-factor correction by synchronous motors in the sizes where such motors are available, and the absence of peaks or overloads.

TABLE II

PUMPING COSTS PER 1000 GAL.

	Gasoline Engine	Electric Motor
Attendant	$0.0081	$0.0081
Power	0.0250	0.0170
Oil and Supplies	0.0005	0.0009
Repairs	0.0011	0.0016
Total	$0.0347	$0.0276

Motion-picture Industry

By I. M. Day and S. C. Leibing
Engineering Department, General Electric Company

I. M. Day

As evidenced by its phenomenal growth, and the ever increasing distribution of its product, there is scarcely an industry in the United States which is more popular than that of the motion picture. Some idea of its magnitude may be obtained from a recent statement by the D. W. Griffith Company:

"The Industry is the fifth largest in the United States. Average daily attendance amounts to eleven million people. Motion picture theaters now total 18,000 and 1200 additional houses are being built in 1920. Box office receipts during 1919 were \$800,000,000 and estimated receipts for 1920 are \$1,000,000,000. This reflects the accomplishment of a twenty-year period."

For several years motion pictures were produced almost entirely in California, because of the quality and duration of the sunlight available. Within recent years, however, methods of artificial illumination have been so greatly improved and developed that sunlight is being superseded by electric lighting. This latter form of illumination can be controlled and directed at will and hence is more useful and reliable than even California sunlight. Moreover, it is always available; and with it effects are possible which cannot be obtained with daylight.

It is not the purpose of this article to give in detail the methods used in the making of motion pictures, but rather to indicate in a general way the scope and magnitude of the industry and the importance that electricity is gradually assuming in the production of pictures.

There are two principal studio centers in the United States, Los Angeles and New York, but in addition to these there are film communities of various sizes at Indianapolis, Syracuse, Chicago, Philadelphia, and at Fort Lee, New Jersey. Jacksonville (Florida) while not at present a studio city of any pretensions gives indications of being in the future a competitor of Los Angeles and New York. There are also studios in Augusta (Maine) and at Film Land City on the outskirts of Boston.

S. C. Leibing

Although the theater is probably the best known and most conspicuous part of the industry, the importance of the studio where the pictures are produced must not be underestimated. The general effects and the photographic quality of the pictures depend to a very great extent on the kinds of light used. There are two classes into which the light is divided: "Soft" lighting, used as a foundation or background, which is usually made up of banks of Cooper Hewitt lamps; and "hard" lighting, which is used to tone up the picture, and for securing various effects not possible with soft light. This hard light is obtained with various types of arc lamps, the most recent addition to which has been the redesign for studio use of the high intensity searchlight, used so extensively by the Army and Navy during the war. With the proper combination of soft and hard lighting the producer is independent of daylight, and the results surpass even those obtained with natural light itself.

For the various types of lights used, including Cooper Hewitt lamps, flood, spot, and high intensity lights, the watts per square foot of illuminated area may amount to as much as 100. In some special cases this figure may even be as high as 400 watts per square foot. Light is used in abundant quantities, for it is of the utmost importance that this one factor shall be of sufficient intensity when the scenes are photographed.

With the exception of general purpose lighting, which is accomplished by the use of incandescent lamps, all the lights used in the studio require direct current to secure the most satisfactory results. Alternating current when passed through an arc causes a flicker which is very undesirable.

Since most power companies furnish alternating current, it has been necessary in nearly all cases to install motor-generator sets to

Fig. 1. A Number of Scenes in the Famous Players Lasky Studio in Long Island City

Fig. 2. Banks of Cooper Hewitt Lamps in a Studio. An example of "soft" lighting

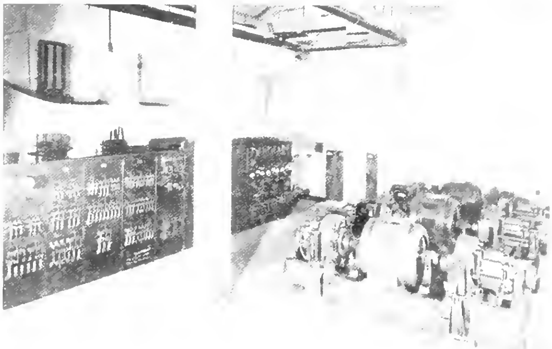


Fig. 3. Three 300-kw., Three-unit Motor-generator Sets in the Substation of the Famous Players Lasky Studio

Fig. 4. Portable Generating Unit for Lighting When on "Location" Work

[illegible] In the larger [illegible] built recently, sets [illegible] 1000 kw. have been [illegible]

[illegible] larger studios are so [illegible] of current is so large

Fig. 5. High intensity Studio Light for one form of "hard" lighting

that ample bus capacity is required. For this type of distribution the three-wire system seems best and is now universally employed. For such an installation a three-unit motor-generator set consisting of two direct-current generators is recommended in preference to either the three-wire generator or synchronous converter, since the demand for light comes so suddenly that the studio electrician does not have time to balance the load properly. The generators of these sets are connected in series to give 125/250-volt three-wire service, and with such an arrangement 100 per cent current can be carried in the neutral.

These sets are usually furnished in sizes of 100, 175, 300, and 350 kw. Sets of double this capacity are sometimes considered for the very large studios. Both synchronous and induction motors are suitable for driving these generators; but on account of the desirable feature of better power-factor, the synchronous motor is becoming more and more popular.

In the smaller studios the lighting load is of heavy demand for short periods of time, but in the larger centralized studios where lighting effects are carried on at several different points, the demand has a tendency to become a more continuous one.

On account of the operating characteristics of Cooper Hewitt lamps, good voltage regulation is necessary. These lamps will operate best on a voltage which does not fluctuate more than five per cent above or below normal, and hence it is very important that the regulation be approximately within these limits.

In most of the large studios there are woodworking and machine shops for the production of scenery, furniture, and the many varied articles that are required in the taking of a picture. In each of these shops a certain number of motors is required.

In the laboratory, where the developing and printing are done, there are many small motors employed for driving revolving drums in the drying room, perforating machines which prepare the film for the projectors, cleaners and blowers for ventilating and air conditioning. For the printing machines a very constant voltage is required and a small size motor-generator set with a counter electromotive force regulator is used.

In addition to the work done in the studio the taking of a picture requires considerable work with outside scenes, called "location" work. Even here artificial illumination contributes important features in securing successful effects in both day and night work. There is in common use a small size portable generating unit of about 100-kw. capacity to supply the direct current for lighting. Sometimes the power for driving the generator can be obtained from a nearby transmission line, but where such power is not available a gasoline or oil engine driven unit is used.

It should be noted that the ratio of the lighting demand to that for other purposes is very large. Moreover, so much expense is involved in the taking of a picture that nothing must be permitted to interfere with the proper supply of light. Its reliability must be assured.

The motion picture industry by the nature of its power demand offers to the central station an increasingly attractive load. As has been mentioned, the demand is high and for the most part occurs during the daytime.

Since the trend is toward centralization of studio activities, this load will have a tendency to become more continuous. A large lighting load during the daytime can be of considerable value to systems where power-factor correction is desired.

Because of the ease with which the elements that are necessary for the production of pictures may be obtained and controlled through the use of electric light and power new communities for the production of motion pictures have grown up in the various parts of the country. In addition to these theatrical productions, motion pictures are being used to a great extent by the industries for advertising and welfare work, and altogether the indication is that the future demand for electric power in cinematography will be considerable.

Refrigeration Load

By A. R. Stevenson, Jr.
Power and Mining Engineering Department, General Electric Company


A. R. Stevenson, Jr.

From the time of the Civil War until about 1890 the city of Baltimore obtained its supply of ice from the Kennebec and Penobscot Rivers in Maine. The schooners which brought the ice to Baltimore returned to the North laden with coal. In this connection a recent note in the *Compressed Air Magazine* is of interest:

"Some years ago there were thirty-six large ice houses along the Kennebec River for the harvesting of natural ice, but their number has diminished and now the end has come as the business is no longer profitable, artificial ice displacing the natural product in all the larger cities."

In Chicago alone the electric power consumed annually by ice and refrigerating plants has increased from approximately eight and one-half million kilowatt-hours in 1913 to nearly fifty-two million kilowatt-hours in 1920. This gives an idea of the tremendous development of the ice and refrigerating industry in the last few years.

How can these increases be accounted for? The cost of labor and transportation has risen in comparison to the cost of power to such a level that it is now cheaper to manufacture ice near the distribution center than to harvest and transport it long distances for distribution.

The original ice plants were steam driven and used practically all of the exhaust steam in the manufacture of "distilled-water ice." As long as it was thought necessary to use distilled water, the steam engine had a great advantage over the electric motor in this field.

But of late years it has been discovered that raw water can be used in the manufacture of ice. Air is allowed to bubble up through the can and, as the ice freezes from the sides inward, the impurities are all pushed to the center. The water in the center which contains all the impurities that might discolor the ice, is pumped out and replaced with fresh water, after which the cake is frozen solid.

With the discovery of "raw-water ice" the steam-driven plant lost the advantage and is gradually being driven out of the field by the motor-driven compressor. The development about this time of the low-speed synchronous motor for direct connection to reciprocating compressors has probably been one of the most important factors in hastening the electrification of ice plants. The low-speed synchronous motor in comparison with other types of low-speed motors, is cheap, has a high efficiency, and the power-factor is unity or leading.

An ice plant should be near its center of distribution, but this is almost impossible with the steam plant because of the smoke and dirt. Also in order to obtain coal cheaply it was very desirable to locate a steam plant on a railroad siding. These reasons disqualified the steam-driven ice plant from being located in a residential district.

But the chief reason for electrification has been that while the price of coal and labor has been going up to double what it was in 1914, the cost of electric power has increased only slightly.

[illegible] a recent article in *Ice* [illegible] the following statistics [illegible] in coal by the use of [illegible]

	[illegible] Per Ton of Coal Burned
[illegible]	4 to 8
[illegible] Ice Plant	7 to 16
[illegible] Ice Plant Electrically Driven [illegible] Power	15 to 28

[illegible] a day when the economies that can [illegible] by superpower systems are being [illegible] much discussed. The foregoing tabulation indicates that a steam-driven ice or refrigeration plant wastes coal because the same amount of ice or refrigeration can be obtained from less coal if central station power is used. This saving in coal is due to the much greater efficiency of the large generating station, but there is still another advantage almost more important. By generation of power on a wholesale basis a great saving in labor is effected. It is no longer necessary for an ice plant to employ a licensed steam engineer and fireman.

It might be thought that fuel oil would take the place of coal. "Rise in Cost of Fuel Oil Has Caused Majority of Pacific Coast Plants to Change from Distilled-water Ice to Raw Water," is the title of a recent article by H. D. Fry in the *Refrigerating World*. This article gives the following statistics:

	Barrels of Fuel Oil Per Ton of Ice
Distilled-water Plant	0.4 to 0.6
Steam-driven Raw-water Ice Plant	0.16 to 0.2

The article further states:

"Comparing the power bills today with the oil consumption of the past, the electric power figures out an equivalent of oil at from 65 cents to 85 cents per barrel. When we figure the present day oil prices, the saving is material." The price of oil at the present time is about \$2.75 per barrel. This shows that the electrically driven plant has an even greater economy over fuel oil than over coal.

Having shown the great advantage of central station power for the refrigeration industry, it now remains to show the great advantage of the refrigeration industry as a load for central stations.

In order to attain the economical manufacture of power, so that it can be sold at low rates and yet leave a profit for the central station, it is necessary that the central station have a good load-factor and a high power-factor.

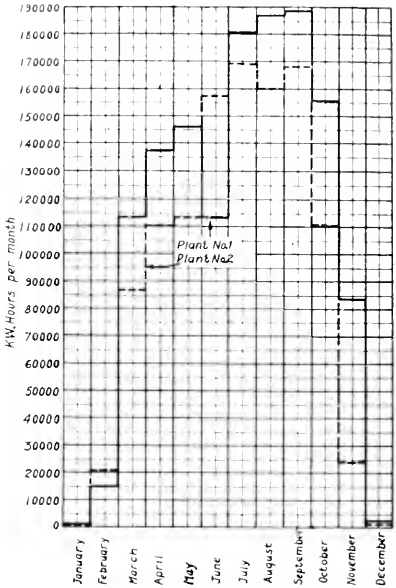


Fig. 1. Load Curves of Two Ice Plants Showing That the Peak Load Occurs in Summer

Ice plants are almost always electrified with synchronous motors. This fact speaks for itself on the question of power-factor.

Mr. Bennis of the United Electric Light and Power Company, New York City, states in the December issue of *Ice and Refrigeration* that from average conditions existing in New York it had been found possible to operate a plant with 90 to 96 per cent load-factor. Mr. Bennis' figures are based on a weekly maximum demand system. Other figures show annual load-factors as high as 70 per cent.

But just as the synchronous motor can be used to counteract bad power-factor existing from other installations, so can the ice plant load be used to improve the bad load-factor due to the daily variation in other loads. Most ice plants and cold storage plants can be shut down for eight hours without an injurious rise in temperature. This is especially true during the winter months when the peak load of the power company occurs between 4:00 p.m. and midnight. In the larger cities the ice plants and refrigerating

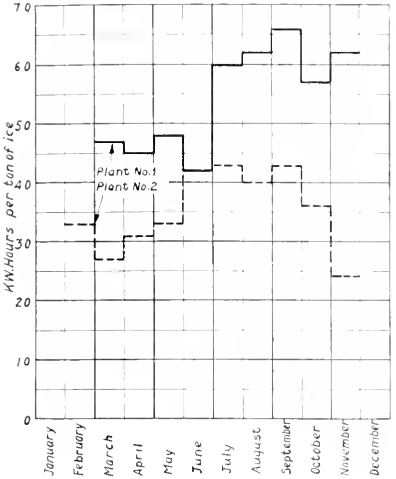


Fig. 2. Monthly Kilowatt-hour Consumption Per Ton of Ice Manufactured in the Plants Referred to in Fig. 1

plants get special power rates for shutting down between these hours during the winter months. This shows how the ice plant can be used to correct the daily fluctuation in load-factor of a power company.

But in addition to this daily corrective effect the ice plant has an annual corrective effect. The load on the central station is greater in winter than in summer, whereas the ice plant peak load comes in summer.

In Fig. 1 are plotted the number of kilowatt-hours per month for the twelve months of the year for two ice plants in the city of Chicago. Of course more ice is made in the summer because the demand is greater, but it also takes more power to make a ton of ice in summer due to the higher temperature of the cooling water. Fig. 2 gives the kilowatt-hours per ton of ice for each of these same plants for each month in the year. The values from which these curves are plotted are taken from a paper read by Mr. W. J. Bray before the National Association of Practical Refrigerating Engineers

So far all that has been and has had to do with large refrigerating plants. There are several cities now which have from 100 to 300 home refrigerating machines, according to the *Electrical World*. This same article gives a table of the residential kilowatt-hours consumed per month for the average home in which a refrigerating machine is likely to be installed.

Period	Kilowatt Hours per Month		
	Lighting	Refrigeration	Total
Average summer months	20	90	110
Average winter months	42	20	62

These figures also show the tendency of the power consumed in refrigeration to smooth out the load-factor of a central station.

It now only remains to roughly refer to some of the newer developments which point toward an ever increasing demand for electric power by this industry. In Chicago the cold storage industry is taking its first step toward central station distribution of cold storage. The Fulton and Market Street cold storage plant, in which last winter were installed two 600-h.p. synchronous motors driving ice machines, will furnish refrigeration for several other large warehouses which are going up in the vicinity. The central lighting plant has been well known for a long time, and the central heating plant is in operation in many places, but here is a step in the direction of a central cooling plant.

Everyone would expect refrigeration in the ice cream factories or the packing industry, but who would expect to find a refrigerating plant in an automobile factory! Yet within the last year Ford has put in a 1000-ton refrigerating plant to cool quenching oil and drinking water.

F. E. Mathews, Past President of the American Society of Refrigerating Engineers, made the following statements in the January number of *Power*:

"In volume of business for the year, 1920 has been a record breaker."

"The importance of the ice industry can hardly be overestimated."

In the same article it is also stated that the United States consumes 100,000,000 tons of ice per year and that there are 496,960,000 cubic feet of space under refrigeration.

On the basis of a population of 105,660,000, this means that the average ice consumption per person per year is 1894 pounds and that there is an average of 4.7 cubic feet of refrigerating space per person.

Three Years Operation at Windsor

By E. H. McFarland

Manager Beech Bottom Power Company

[illegible] carried out jointly by the American Gas & Electric Company and the West [illegible] is in many respects a new departure in the central station industry and [illegible] due to the sound engineering and business policy of the owners. The [illegible] of Windsor indicates that all apparatus in such stations may be subjected to unusu[illegible] prolonged conditions of operation. The economic importance of keeping each [illegible] boilers, turbine, generator, condenser and auxiliary apparatus, in service at [illegible] prevents the shutdown of individual parts for minor repair and maintenance [illegible]. However, it is gratifying to know that the standard types of apparatus installed have [illegible] their ability to stand up under these exacting conditions.—Editor.

The information presented in this article concerns the initial three years operation of the Windsor property. This is one of the first large steam electric generating stations located at the source of fuel supply and sending the transformed energy to points of use by high-tension transmission. Because of the interconnection of the various systems served, and the manner in which they are operated, the station produces continuously from thirty to fifty per cent more power per generator unit than similar undertakings at present serving the larger cities.

First work on the site was started in January of 1916, and the initial operating trials occurred in August of 1917. During the period of the World War and until just recently the insistent demand for power by the systems served has been such as to cause a continuous vigorous drive on construction progress, operation, etc., to keep up with the load requirement. Necessarily certain changes in the equipment that were found to be desirable required long periods to effect, as they had to be accommodated to the infrequent periods when equipment could be spared from service.

The present plant generating equipment having a capacity of 120,000 kw. consists of four 30,000-kw., 60-cycle, 1800-r.p.m., 11,000-volt, 3-phase turbine-generator units, each with its complement of four 1250-h.p. water-tube boilers with condensers, heaters, switching equipment, etc. The average steam con-

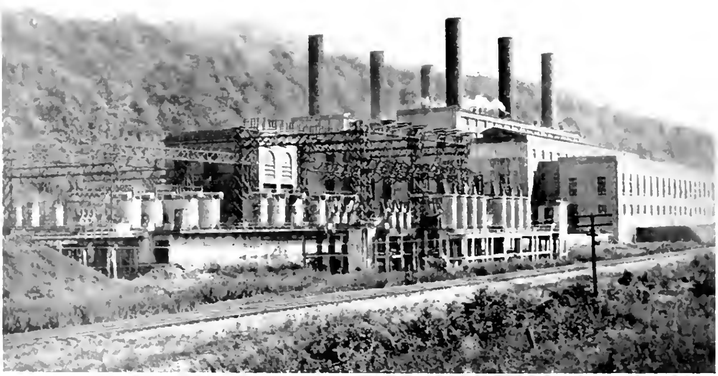


Fig. 1. Windsor Power Plant Looking Southeast

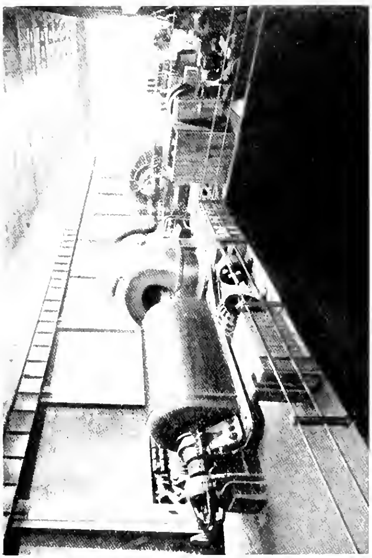


Fig. 2. Generator Room Showing Four 30,000 kw. Curtis Turbo-generators

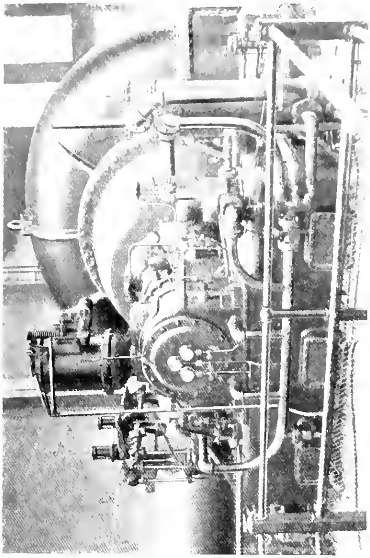


Fig. 3. Turbine End of 30,000 kw Turbo-generator Set

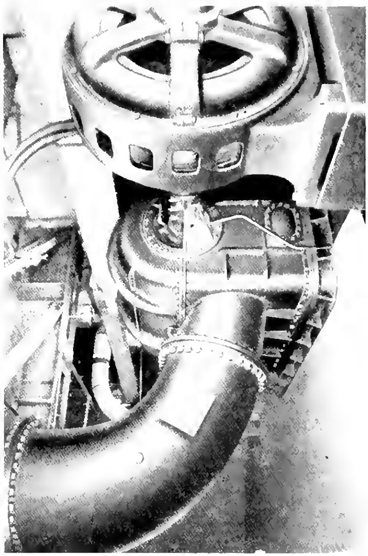


Fig. 4 Induction Motor Condenser Circulating Pump

Fig. 5. Control and Switchboard Room

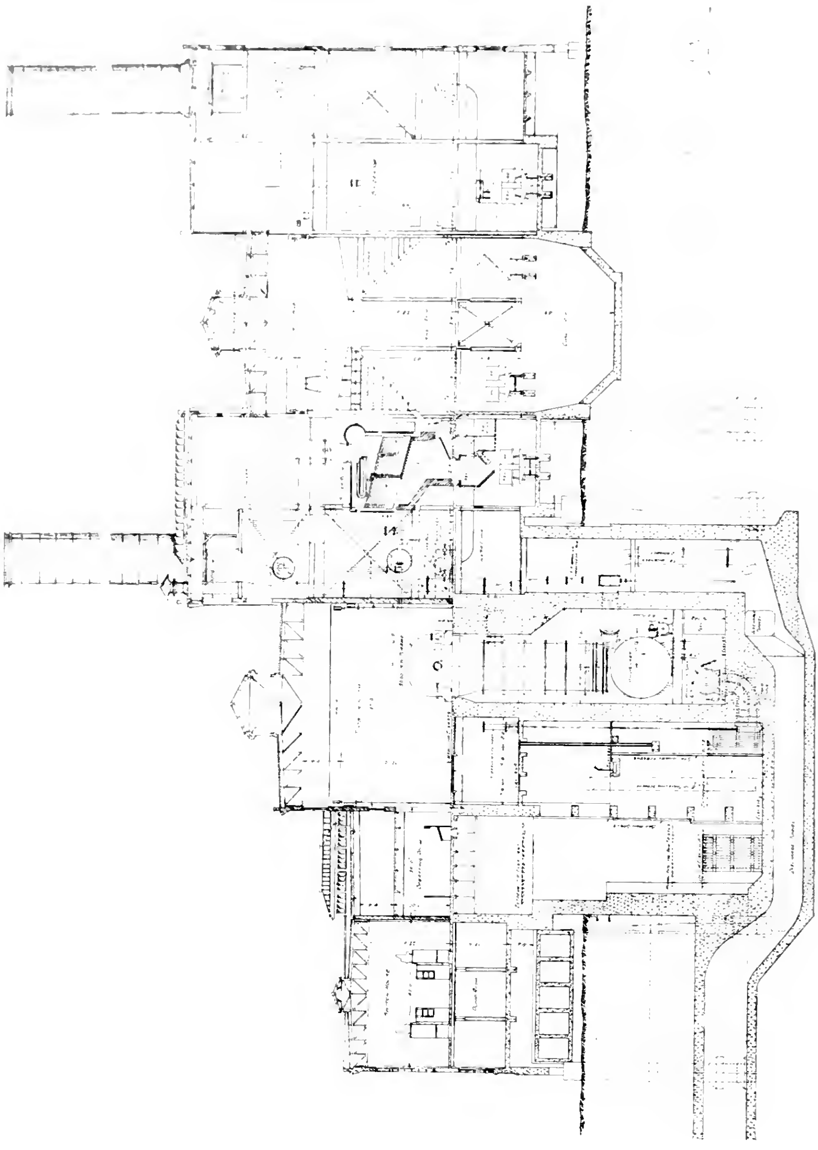


Fig. 6. Cross Section of Windsor Power Station

ditions at the turbines are 230-pounds gauge, 650 deg. F. temperature, and one inch absolute back pressure. From six to seven kilowatts of generation is allocated to each rated boiler horse power, and consistent driving of boilers at continuous overrating is practiced.

The table demonstrates the activity of the apparatus over an extended period. During the bituminous coal miners' strike in November and December, 1919, the railroad labor difficulties in the spring of 1920, and other instances when fuel supply to other plants interconnected with Windsor was reduced, some remarkable operating records resulted.

The Windsor property is a joint enterprise by the Ohio Power Company (a subsidiary of the American Gas & Electric Company) and the West Penn Power Company, and the power plant is operated as the Beech Bottom Power Company.

at Akron, Ohio; and the Massillon Electric Company, Massillon, Ohio.

The reservation of capacity by the West Penn Power Company is 30,000 kw., which through their transmission system is tied in with the following generating plants: Wheeling Traction Company, Wheeling, West Virginia; West Penn Power Company, Springdale, Penn., and Connellsville, Penn.; and in turn there is provisional exchange of power between the West Penn Power Company and the Duquesne Light Company of Pittsburgh. In general the Windsor plant, using favorable local resources, transforms energy of fuel into electric energy and delivers it to the transmission systems for these localities, which otherwise would have to resort to the use of some thirty or more railroad train crews with perhaps 500 to 700 railroad cars continuously devoted to coal transportation service to

Operation Factors at Windsor	Year 1918 Per Cent	Year 1919 Per Cent	Year 1920 Per Cent	30 Days Nov. 19 to Dec. 19, 1919 Per Cent	One Day Dec. 4, 1919 Per Cent
Kilowatt Hours Generated / Max. Continuous Station Capacity × Total Hrs. = Ave. Station Generating Factor	63.2	66.3	60.2	82.0	93.5
Total Hours Installed Station Capacity Operative / Total Hours = Ave. Station Availability Factor	75.2	78.6	81.5	88.8	100.0
Kilowatt Hours Generated / One Minute Daily Peak Loads × Total Hours = Ave. Station Load Factor	86.3	82.3	81.4	90.8	94.5

First Unit in Service, August 19, 1917; Second, January 16, 1918, Third, May 29, 1919; Fourth, September 15, 1919.

The power plant is located at Beech Bottom, West Virginia, on the Ohio River, approximately ten miles above the city of Wheeling, West Virginia, use being made of river bottom lands immediately adjacent to the field of coal that is being mined.

The busbar voltage of 11,000 is increased by outdoor high-tension substations on the property to distribution voltages of 22,000, 66,000 and 132,000 volts, depending upon the distance from Windsor to the various localities served. The reservation of capacity by the Ohio Power Company is 90,000 kw. of the present installation, and through their system of transmission the plant is tied in with generating stations of the Wheeling Electric Company at Wheeling, West Virginia; the Ohio Power Company at Canton, Ohio; and East Liverpool, Ohio, the Northern Ohio Traction Company and the B. F. Goodrich Company

produce the added amount of energy at their plants.

The present coal mine opening had been in service a number of years before the property was acquired and plant construction started. The seam mined is bituminous Pittsburgh No. 8, approximately five feet thick. The mine entries are about 230 feet above the elevation of the boiler room floor, the coal is brought down by gravity plane haulage, prepared for stoker use at the tipple, and transported about 2000 feet by steam railroad equipment, using side-dump cars emptying into pits in the boiler room basement. Growth of plant demand within the past year requires more coal than the original mine haulage facilities can furnish and the following improvements are in course of completion: New mine entries are being driven through the hill at the side of the plant, intersecting with the pr[illegible] tipple is to be lo[illegible] as received is to be [illegible] impurities, prepared for [illegible] assistance of gravity in breaking [illegible] crushing, and transport[illegible] or direct to the overhead [illegible] boilers; surplus coal is to [illegible] belt and reclaimed back [illegible] belt by a traveling crane as [illegible] may require, at a storage site over which the conveyor belt will travel. The result will be continuous motion of the coal from the working places in the mine to the boiler room, with a minimum of operations.

handles coal. In operating the plant at high continuous ratings, we find a much larger boiler ash hopper capacity is desirable. With the property grading completed, it is the intent to use other methods of ash transportation.

It must be remembered that, for good economy, the flow of cool water into a power plant must be from 500 to 600 times the rate of flow of coal into the plant, and the Ohio river serves us well in this respect. The maximum difference of record between flood stage and low water in the Ohio river at the plant site is forty-nine feet, and this accounts

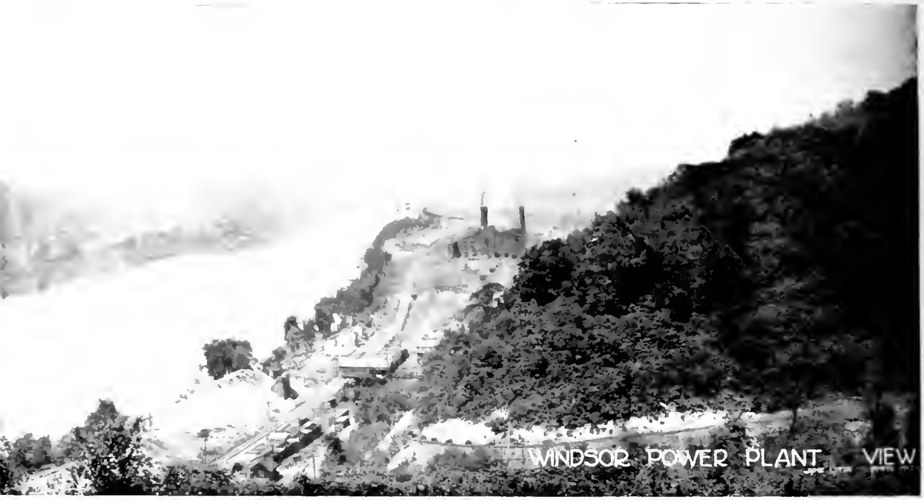


Fig. 7. Panoramic View of Windsor. Power Plant and Tipple on the Left, Located

In addition to enabling a production of coal sufficient to meet present plant requirements or logical extensions, it will dispense with short-line steam railroad haulage, always an expensive method. Sufficient coal for fifty years demand is under reservation. The coal supply of the plant is further protected, as required, by receipts of coal by railroad, towage on the Ohio river, and motor trucks from coal mining operations in the locality.

Ash is at present disposed of in grading the low elevation plant property above river flood stages, use being made of steam railroad equipment of the type that at present

for the use of deep pits, the location of the condensing equipment at the bottom, and material lengths of exhaust piping from them to the turbines. Variations of from twenty to thirty feet in the river are not unusual during certain seasons of the year and we have had occasions when loose material, such as tree limbs, timbers, fencing, dead plant growths, etc., washed off of the river bottom lands has caused a large amount of extra work about the screen intakes to dispose of this material. A floating fender which guards against the larger debris, certain ice conditions, etc., has proved helpful.

During the three-year period of persistent operation at material overrating of boiler plant equipment (boilers, stokers, economizers, etc.), it was necessary to contend with and gradually correct certain faulty conditions and still meet the service demand requirements. There was continual failure of brick work and furnace linings, which required frequent renewal. A change of shape in some of the furnace walls and a material increase in capacity of the induced draft fans making negative pressure conditions possible at all times over the fuel bed reduced the service outage and maintenance expense to a nominal value. The failure of boiler tubes over the fire was particularly frequent, and cleaning of boilers, economizers, etc., was a continual operation due to periods of excessive leakage of the surface condensers, admitting raw water with its river silt content into the system. Changes have also been made to the boiler room structure and fan equipment which have improved the arrangement for the large maintained air demand of the stoker fans.

The first turbine units furnished, which were of a new design constructed and installed during the war period with its attendant abnormal conditions, were not entirely free from faults in workmanship and materials. Each unit was immediately called upon for all it was good for as soon as construction work reached the point where the machine was operative. Substitution of steel for cast iron where subjected to high steam temperatures later became necessary. Because of difficulty elsewhere with diaphragm deflection under maximum load conditions, and to insure uninterrupted service to essential industries, upon the manufacturers' recommendation the first two units were operated at loads not exceeding two-thirds of their rating. Subsequent experience indicated that the restriction of capacity was ultra-conservative. It was necessary to regularly operate one unit two and one-half years and the other three years before there was convenient opportunity to make the desired changes. During this period these turbines carried their maximum available load eighty per cent of the elapsed time and would have made even a better record if it had not been necessary to conduct maintenance work on their condensers, boilers, oiling systems, etc.

Alongside the Ohio River. Coal Mine on Right with Gravity Railway Between

Though air washers are in use for the generators, the long periods of continuous opera-

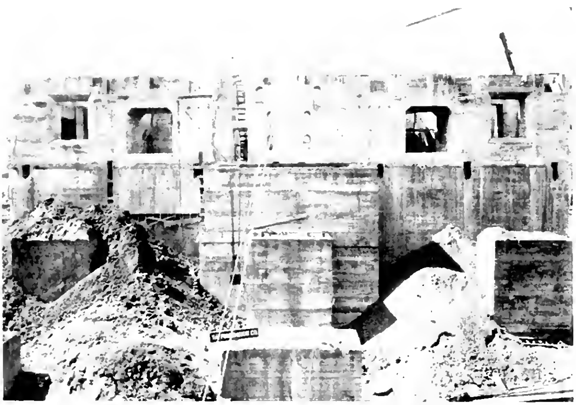
[illegible] accumulation of [illegible] caused some [illegible] being made of a [illegible] on one of [illegible] all will be later [illegible] and [illegible] hing and cooling of [illegible] will largely reduce [illegible] in the windings. [illegible] difficulty with leakage [illegible] condensers which caused [illegible] expense was due to the [illegible] tube packings which did not [illegible] water conditions. As a [illegible] loosened, vibrated and crystallized, eventually failing. The use of different [illegible] annealing and substitution of [illegible] proved effective in correcting this condition. All auxiliary apparatus is motor-driven with the exception of the boiler feed pumps.

In general all switching on circuits and feeders carrying load is accomplished with the 11,000-volt switching equipment. Spare transformer and switching equipment has been ample. Facilities exist for rapid disassembly and inspection of this apparatus, and frequent examinations have resulted in nominal maintenance expenditure. The transmission system has been remarkably free from service interruption.

Various methods of prompt communication exist between the switchboard room, which is in charge of the load dispatcher, and the various power plants, substations, and centralized points of transmission which the plant serves. In general the load dispatcher at Windsor at frequent intervals informs all who are interested of the maximum amount of power that is available from the busbars at the plant, and this is distributed as needed to each of the receiving systems in accordance with the percentage participation and as their interests may demand. The load dispatchers at the various locations, in accord with one another and having knowledge of the variation of load value on the interconnected systems, the condition of apparatus, and the relative merits of points of generation, distribute the power flow through the transmission system within the scope of its capacity; and an interruption of generating equipment at any point at any time is very seldom noticeable to the ultimate consumer.

In attaining the nearest approach to a condition of 100 per cent readiness to serve from all equipment, at a location which in transportation time is remote from city facilities, it has been advisable to provide housing accommodations for 50 per cent of the entire operating personnel of the plant and the mine, and also a building for warehousing and repair of equipment which is of much greater size and more diverse facilities than is usual for metropolitan plants.

The operating record of this station demonstrates the stamina of apparatus under exacting service which may become common to enterprises of this character.



Windsor Power Plant Under Construction. East Elevation of Condenser Pit

Industrial Heating and the Central Station

By E. H. Horstkotte

Power and Mining Engineering Department, General Electric Company

E. H. Horstkotte

ALTHOUGH still in its initial stages as compared with its ultimate development, the adoption of electricity as a heating agency is proceeding at a phenomenal rate and the Central Station has every reason to feel very optimistic concerning its future. Every day one sees new applications and, not infrequently, new processes and products developed by its use. Even now in some sections of the United States this load is as large as the combined motor and lighting load of the stations supplying the power. In the Niagara Falls district fully ninety per cent of the electric power developed is consumed in heating loads. Many central stations have found it necessary to increase their generating capacity to handle the increased demands of their customers arising from this source. At the present time it is being given a greater impetus by the ever increasing costs and difficulties in transportation of coal and oil, by the gradual depletion of our natural gas resources, and by the development of our long neglected water power.

Electric heating may be divided into three classes, viz., industrial, electrochemical and electrometallurgical, the last two of which are discussed in other articles of this issue. Broadly speaking, in industrial applications heat is applied to the process or product without effecting a chemical change, and in most cases at a comparatively low temperature. In the electrochemical and electrometallurgical processes, however, the material to which heat is applied has very different characteristics, both physical and chemical, before and after the application.

It is almost impossible to name a single factory that does not use heat at some time or other in the process of manufacture and when compared with the other power requirements of the plant, the energy required for the heating load measured in B.t.u., is usually far in excess of that required for the motor and lighting load. In nearly every one of these applications electricity as the heating agent has some advantage over other methods of heating. The field of electric heating will continue to grow as experience and science work out the correct design and proper method of application for the particular process involved. Even now the scope of application is very extensive, as the following list indicates:

Annealing furnaces
Back rounders
Bacteriological incubators
Batch warmers
Branding irons
Broilers
Burnishers
Butter warmers
Button die heaters
Can capping machines
Car heaters
Case making and covering machines
Cauterizers
Celluloid softeners
Chocolate warmers
Chocolate trays
Cigar lighters
Clothes dryers
Coffee roasters
Coffee urns
Collar and cuff molding machines
Core ovens
Corn poppers
Corset irons
Crimping machines
Cuff irons
Curling irons
Dental furnaces
Dye tank heaters
Dipping tanks
Disc stoves
Drying ovens
Enameling ovens
Envelope gum dryers
Fan dryers
Film and print dryers
Flash heaters
Flatirons
Food warmers
Form heaters
French irons
Gilding wheel heaters
Glue creasing tools
Glue heaters
Glue pots
Griddles
Hair dryers
Hand felts
Hand shells
Hanging bags
Hosiery forms
Heating pads and blankets
Hot bath cabinets
Hot plates
Incubators and brooders
Indenters and burnishers
Japanning ovens
Knurling machines
Laundry irons
Lining cementers
Linotype and monotype pots
Machine irons
Manglers
Matrix dryers
Metal melting pots
Muffle furnaces
Ovens
Palette heaters
Paper seal moisteners
Patent leather machines
Peanut roasters
Peanut warmers
Pipe thawing apparatus
Pleating machines
Rectifier tube boilers
Resin heaters
Rivet heaters
Roofing pitch kettles
Sealing wax heaters
Shelf heaters
Sherardizing ovens
Shoe relasters
Sleeve irons
Soldering irons
Solder pots
Solution tanks
Stamping and embossing presses
Starch cookers
Steam boilers
Sterilizers
Stitchers
Tailor irons
Tank heaters
Teapots

Fig. 1. Battery of Eight Heat Treating Furnaces Installed at Packard Motor Company, Detroit, Mich. First six furnaces operate at 1650 F. Last two furnaces operate at 1100 F.

Fig. 2. Vitreous Enamel Furnace. Working chamber 10 ft. deep, 4 ft. wide, 2 ft. high, connected load 140 kw., 220 volts, 3 phase, 60 cycles, 1,?00 F. Operation, St. Louis Brass Company, St. Louis, Mo.

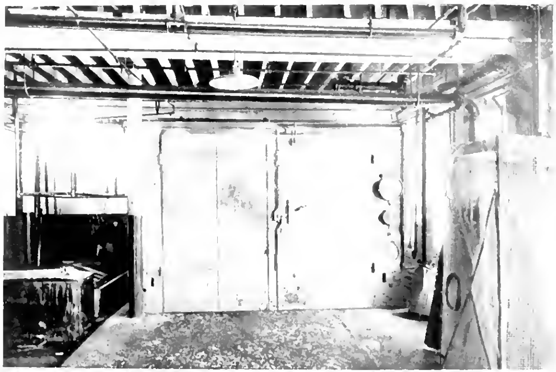


Fig. 3. Japan Baking Box Type Electrically Heated Oven, 8 Ft. High, 12 Ft. Wide, 18 Ft. Deep. 150 kw. connected. Chevrolet Motor Car Company, Tarrytown, N. Y.

Fig. 4. Sherardizing Ovens, Building No. 89, Schenectady Works

Tempering furnaces	Velouring stoves
Test tube heaters	Vulcanizers
Thread waxing machines	Waffle irons
Toasters	Water heaters
Tube crucible vacuum furnaces	Water stills
Turn and welt machines	Wax burning-in irons
Varnish drying ovens	Wax knife heaters
Vat dryers	Welding apparatus
Velvet marking irons	Welders
	Yarn conditioning oven

The widespread use of electric heating can be attributed to the immense demand for heat, the great lack of efficient fuel apparatus, and the many disadvantages of fuel transportation, storage and combustion. Electric energy can be transformed directly into heat energy at one hundred per cent efficiency. It does not contaminate the atmosphere. It is clean, safe, sanitary, flexible and easy to apply. Greater quantities and more intense heat can be produced electrically in a given space than by any other known means. It can be measured and controlled both as to temperature and quantity more readily than any other source of heat energy.

Fig. 5. Electrically Heated Core Baking Oven, Showing Loaded Truck and Electric Heaters. Oven 10 ft. long, 5 ft. wide, 7 ft. high, 72 kw. connected

In considering the various types of heat sources for an industrial plant it usually develops that the energy costs are only a small part of the total cost of the product, and other items, such as better product, less waste, cost of installation, labor charge , etc., must be considered. Otherwise, many manufacturers of automobile bodies who had gas heated ovens installed would not have been justified in discarding them and replacing them with electrically heated ovens. In the manufacture of an enameled product the

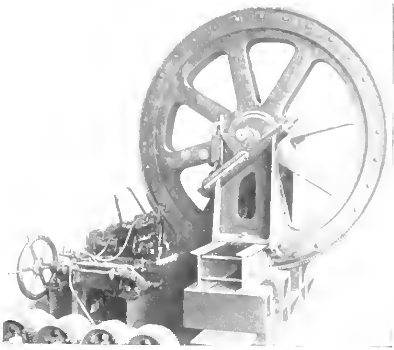


Fig. 6. Welding End Ring of Rotor, 36-pole, 1400-h.p. Induction Motor

cost of the enamel, on the labor alone, is generally higher than the cost of the energy required for baking it. Further, the cost of reworking one piece, spoiled in the baking process, may be as much as that of the energy required for the entire bake. The method which increases to a maximum the intrinsic worth of a specified product may make the process having the higher manufacturing cost the cheaper process in the end.

In the majority of industrial heating applications the maximum temperatures required do not exceed 1000 deg. C. Exceptions to this are mostly in the transformer heating devices. In the low temperature applications the transformation of electrical energy to heat energy is usually obtained by passing electric current through a metallic resistor having a comparatively high electrical resistance and also a high resistance to oxidization. This type of load is an ideal one for the central station. It is adaptable to either direct or alternating current. In case of alternating current, the load can be distributed evenly over the different phases, resulting in a well balanced load. Also as the load is entirely resistance the power-factor is very high.

In the transformer heating devices, such as rivet heaters, butt welders and spot weld-made a part ... that ... absorbed ... the appa- ... and inter- ... power- ... varies

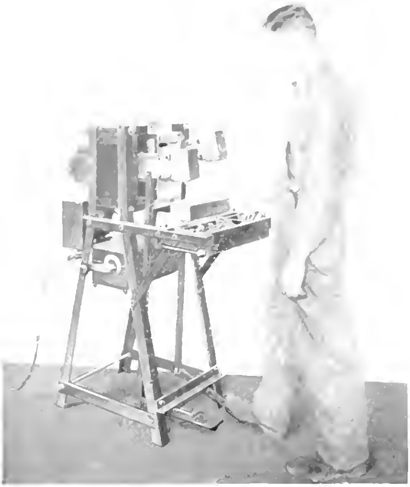


Fig. 7. Electric Rivet Heater, 15 Kw., 220 Volts, 75 Amp., 60 Cycles.

widely with each installation. Where there is considerable power involved, voltage fluctuations may be caused. This is usually overcome by interposing a motor-generator set between the transformer and source of supply, which not only acts as a buffer or stabilizer between the load and source of power but also distributes the load evenly on all the phases.

The greatest benefit, however, which accrues to the large central station from a large industrial heating load is the high diversity factor obtained, and its effect upon the load factor. An industrial heating load is usually made up of a large number of small loads and it is very evident that the generating capacity of the station supplying, for instance, one hundred one-kilowatt loads for 10 hours will be much less than a station supplying the same number of kilowatt-hours to a load for one hour. In the average central station the power demand is by no means constant throughout the day and much less so at night. Valleys and peaks occur more or less regularly in the power demand as shown by the station load curve. It follows then, if the load curve can be smoothed out, that is, a demand created for power during the off-peak periods, that lower rates should be offered for such power. In many cases large demands for industrial heating load can be arranged for during these off-peak periods at rates which make it very economical and advantageous for both the central station and the consumer. A large portion of the heating can be done at night, for which a rate materially lower than the day rate may be secured.

Many factories purchase their power on a maximum demand basis. When this sort of contract exists the factory virtually buys a constant power load for 24 hours having a maximum demand value. The factory consumption of power is usually accompanied with peaks and valleys, and in such cases the valley portions of the load curve may be filled in with heating devices at no additional cost for power. Again where power is sold on a maximum demand and kilowatt-hour basis

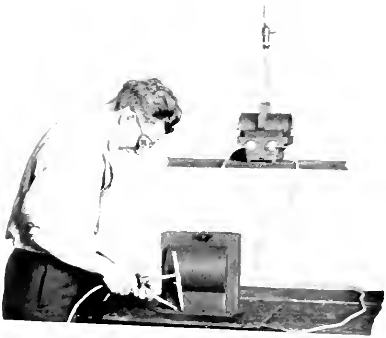


Fig. 8 General Electric Pyrotip Soldering an Alloy Flange to Sheet Iron Tank.

combined, it frequently happens that the valley portions of the load curve can not only be filled but the total power consumption of the plant may be increased by taking on an electric heating load to such a value that this load is obtained at a rate considerably lower than that for the motor and lighting load.

Automatic Arc Welding

By H. L. Unland

Power and Mining Engineering Department, General Electric Company

H. L. Unland

THE automatic arc welder is an electro-mechanical device for feeding a continuous electrode wire into a metallic welding arc, the rate of feed being governed by the electrical conditions in the arc. The function of the device is two-fold: First, it permits the use of a continuous electrode and thus avoids the frequent stops and the wastage of short ends of wire when electrodes are changed. Second, it replaces the muscular inaccuracy of a manual welder's arm and wrist by the steady motion of a mechanical device which is not subject to fatigue or illness.

Various investigators have reported that the electrode loss due to waste ends is from 15 to 20 per cent of the total, corresponding to a waste of from two to three inches when a 14-inch electrode is used. In many cases, however, it will be found that the waste ends run from three to five inches in length. The loss of time, in itself, is not particularly serious. An average of 80 seconds is required to deposit one electrode with from 5 to 20 seconds lost in changing electrodes. This interval, however, gives the metal last deposited an opportunity to cool, with the result that the welder must, in effect, start an arc on a cold spot. Unless care is taken the old crater is not entirely fused, with the result that a porous spot is merely covered over with a thin coating of metal. Most of the leaks in vessels are found to occur at these points.

Uniformity or steadiness of conditions in the arc is universally accepted as a requisite for sound welding. Due to the uniformity of the automatically regulated arc, it is possible to weld at a rate greatly in excess of that possible in manual welding.

The automatic welder consists of two parts, a welding head and a control panel. The welding head consists of a pair of feed rolls and a small direct-current motor, with suitable gearing between. The feed rolls serve to force the electrode wire along and also to introduce the welding current into the wire. The panel is provided with the necessary instruments, rheostats, relays, and contactors to indicate the conditions in the welding arc circuit, and also to adjust and regulate the speed of the feed motor in order to maintain the arc voltage constant at any desired value throughout a considerable range.

Since the automatic welder merely replaces the manual operation of the electrode, a suitable source of welding current is necessary. This may be of the single-operator variable-voltage type or of the multi-operator constant potential type. In either case, for a given adjustment of the welding circuit, the current and consequently the rate of deposition will remain constant as will the arc length if the arc voltage is held constant by varying the speed of the electrode feed. This briefly is the principle of operation of the automatic welder. The connections and control equipment are such that an increase in the arc voltage causes an increase in the speed of the feed motor, and consequently the electrode is fed more rapidly to the arc. When the arc voltage reaches the normal value the motor again resumes its normal speed. The converse takes place when the arc becomes too short.

Since the device is only intended to feed the wire into the arc, a travel mechanism is necessary and must be provided to steadily move either the work or the welder in order to have the arc progress along the desired line of weld. A manual welder will go slowly at points where the edges of a seam gap apart and will fill the opening by a different motion of the electrode. This is impossible with a machine and therefore care must be taken to obtain suitable preparation for the weld. This takes the form of preparing and carefully aligning and clamping the edges where two edges of plate metal are to be joined. When the metal to be joined is thin, the edges need not be beveled. A section of heavy metal is often used for backing up a weld. This may be for the purpose of securely holding the work while it is being welded, or to prevent molten metal running through and forming drops on the back of the weld, or else to prevent the arc burning through the sheet. The second use depends on the backing strip for mechanically holding the molten metal

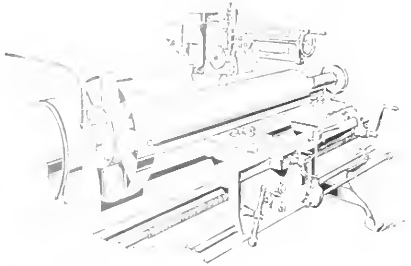


Fig. 1. Lathe Used as Travel Mechanism for Automatic Arc Welder. Lead screw provides straight line motion

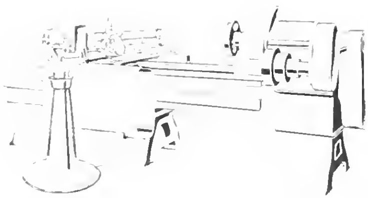


Fig. 2. Same as Fig. 1 with Work Supported from Carriage and Welding Head Mounted on Stationary Pedestal

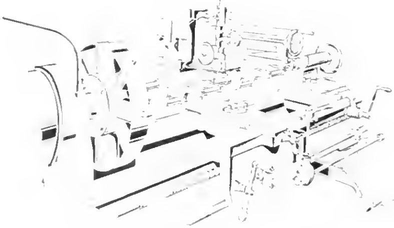


Fig. 3. Same as Fig. 1. Cross Feed Used for Obtaining Motion of Welding Head

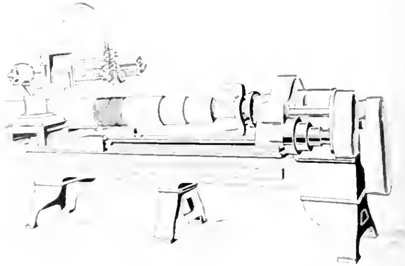


Fig. 4. Depositing Spiral Weld by Means of Lathe

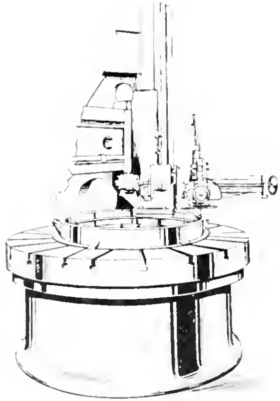


Fig. 5. Automatic Welding Head Supported on Boring Mill to Obtain Circular Weld

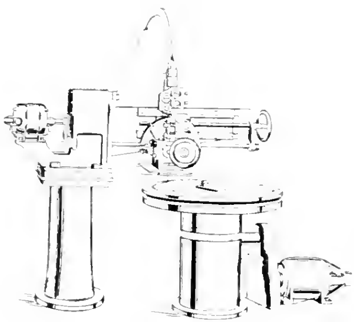


Fig. 6. Turntable Used for Circular Weld

in place, while in the third use the heat conductivity and mass of the backing are depended upon. The second use is applicable when medium or heavy plates are being welded, and in this case the backing strip need not accurately bear on the plate at all points. Considerable variation is usually permissible. The third use is a necessity where thin sheet metal is being welded and this further requires that the sheets touch the backing strip at all points along the weld.

Since copper has high heat conductivity and is easily formed, and furthermore since molten iron or steel does not tend to weld to copper, this material is found to be most suitable for backing up a weld. The backing strip of copper may be supported on a steel shape if greater strength is required. In some cases the backing may be of steel.

Since the arc progresses, by means of the travel mechanism, along a predetermined path, it is evident that the piece to be welded should be accurately held in shape and in position. This at once suggests the use of clamping and supporting jigs and fixtures, which are of material assistance in handling pieces for welding. The cost of the fixtures becomes of negligible importance when the number of pieces welded is large. The principal field for this device is the production, by welding, of duplicate objects in considerable quantities.

In any given application the success will depend in a large measure on the use of a suitable travel mechanism. The majority of production welds fall into one or both of two simple classes. A straight line weld is the simplest form and will be found to include the greater number of welds. A circular weld is another simple form which is frequently used. A combination of these two provides the spiral weld. There will also be found many cases where the weld follows an irregular or more complicated path, and special means must be provided to care for such applications.

Examples of straight-line welds are shown in Figs. 1, 2, and 3. In the illustrations the work shown as being welded is immaterial. The form of weld and method of obtaining the corresponding travel are the features to be emphasized. In Fig. 1 the work is shown as supported between lathe centers with the welding head mounted on the carriage. By using the lead screw on the lathe, the carriage and welding head are moved along the line of weld. Should the work be too large to be supported in this way it may be held on stationary supports behind the lathe, the welding head turned around, and the same methods used. Fig. 2 shows the welding head supported on a stationary pedestal and the work carried on a saddle supported from the carriage. The lead screw is used for obtaining the desired longitudinal motion.

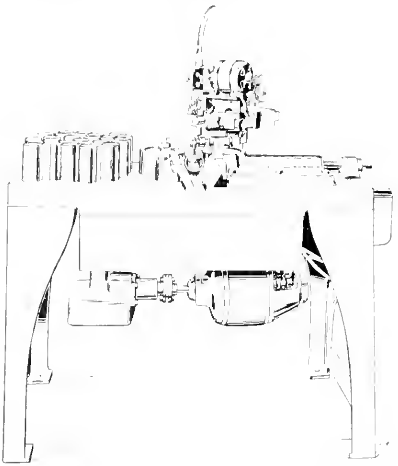


Fig. 7. Travel Mechanism for Welding Tubing

In Fig. 3 the work is shown held stationary between the centers and the cross feed used to obtain the desired motion. The arc is moved back along the work to the end of the weld when the motion of the feed is reversed. At the same time, the carriage is moved slightly in order to deposit a weld beside the first bead. This method may be used for building up low sections or worn spots.

In building up a section of a shaft a spiral weld is deposited as shown in Fig. 4. The shaft is slowly revolved between the centers and at the same time the lead screw advances the carriage bearing the welding head. For the operations thus far described a lathe is entirely suitable although for the simpler motions it is possible that less expensive devices may be made up in some cases.

Other machine tools may be called into service to support the welding head and obtain the desired travel motion as indicated in Fig. 5 in which a boring mill is shown.

In some cases special equipments will be required. For example, the small turntable shown in Fig. 6 may be produced at a very low cost where circular seams only are to be welded.

[illegible] of a pair [illegible] moving short [illegible] a longitudinal [illegible] Fig. illustrated is [illegible] would be just [illegible]

[illegible] machine for [illegible] of large tanks. [illegible] on an I-beam [illegible] strip. In

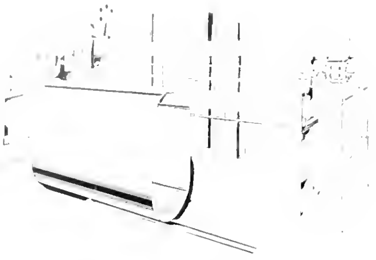


Fig. 8 Welder for Large Tanks

this unit the head is mounted on the carriage, as is the reel of electrode wire, and is driven through a splined shaft by the motor shown at the right end of the machine. The travel of the carriage is obtained by means of a long screw located between the upper supporting beams and driven by the travel motor at the left of the illustration. Such a device will handle a large variety of shapes and sizes of tanks. For welding seams having neither a circular nor straight line path, the machine shown in Fig. 9 has been developed. In this case it is desired to weld the bottom seam of a tank similar to the one shown in Fig. 8. The outline of this path is made up of practically two semi-circular ends with tangent sides. A rack is laid out having its pitch line on the line of the desired weld. A small pinion engaging this rack moves the line of the weld past the point of contact at a constant speed. The arc is held stationary over the point of contact between the pinion and the rack and therefore the work is moved past the arc at a constant rate. The principle of this device may be applied to a large variety of applications where the weld follows a more or less complicated path.

In addition to the methods outlined, there will also be found a great many applications where the use of cams, etc., will be satisfactory and successful travel motion obtained. In all cases, however, it is essential that the travel motion be uniform in speed; and it is also desirable that it be possible to adjust the speed of travel over a considerable range by small increments, in order to obtain the exact speed at which the operation is most successful. This characteristic is best obtained by the use of an adjustable-speed direct-current motor which may be operated from any available power-circuit, or in many cases, may be operated from the generator supplying the welding current. On the panel controlling the welding head there is provided an interlock which may be used to operate the starting equipment of the travel motor. In this way when the arc starts, the travel mechanism will automatically be started and as soon as the arc stops, for any reason, the travel motion stops also. It is desirable that dynamic braking be used to stop the travel and prevent drifting, in order that the arc may re-start at the point where welding ceased.

Fig. 9. Mechanism for Obtaining Complicated Travel Motions

By the use of the automatic welder it is possible to deposit metal, and consequently to weld, at a rate from two to five times as fast as in manual welding. One cause is that a continuous weld is made over the whole length. In this way the welding equipment is working at a high load factor instead of the usual factor of 50 to 60 per cent encountered in manual welding. The steadiness of the arc produces the best quality of deposited metal. However, these valuable qualities may be entirely neutralized unless sufficient pains are taken to provide a suitable travel mechanism.

Apply Arc Welding to Reduce the Scrap Pile

By B. C. Tracey

Power and Mining Engineering Department, General Electric Company

B. C. Tracey

In these days of retrenchment, every manager is constantly alert to the necessity of cutting production costs by improving methods of manufacture and eliminating waste. The size of the junk pile is one sure indication of the success attending his efforts. Heretofore little thought has been given to reclaiming broken or imperfect parts since it is much easier to consign such parts to the scrap heap and draw on the Stock Department for new ones. This may apply to the things produced or the machinery which produces them.

For the reclaiming of metal parts the electric arc welding process furnishes an inexpensive and thoroughly practical means for their repair. The size of the part to be welded is limited only to the skill used by the operator in the preparation of the piece before welding and the manipulation of the electrode during the welding process. The following case is typical of a number of other successful applications of similar magnitude:

"*Repairing Waterwheel Runner by Electric Welding:* Repairing a worn waterwheel runner by electric welding was found to add 350 kw. to the power available from an old 3000-kw. wheel in the Naches Powerhouse of the Pacific Power and Light Company, near Yakima, Washington. This is a 36-in. Victor turbine built by the Platt Iron Works. It is directly connected to a 3000-kw. General Electric alternator. The runner on this unit is of bronze, and several months ago serious pitting took place so that the discharge ends of the vanes were pitted clear through, and the bases of the vanes pitted so that one broke out, cracking several others before the machine could be brought to a standstill. A thorough examination was made, and it was found that the clearance on the discharge end of the runner was 0.22 in., while on the opposite end it was 0.14 in. These clearances were too great.

"At first it appeared that it would be necessary to junk the runner. However, electric welding was tried and 168 pounds of bronze were used to build up the runner where it had been pitted, and also at the clearances. The clearance rings were then removed and machined after which the runner was put in a lathe and the clearance machined to the proper size. The vanes were smoothed by means of a small electrically driven emery wheel and finished off with a file by hand where possible. The shaft also was built up and machined to size. A test showed that the power of the station was increased 350 kw. by the changes."*

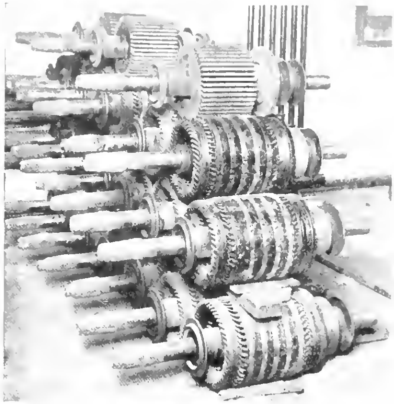


Fig. 1 Worn Armature Shafts Built up by General Electric Constant Energy Welding Machine, Showing One Armature Shaft Machined

If welding had not been employed, the approximate cost of replacing the defective runner parts would have been $2750, divided as follows:

Bronze runner . . .	$2250.00
Clearance rings . . .	500.00
Total	$2750.00

* From *Electrical World*, April 2, 1921, p. 769.

... airing by arc

[illegible]	\$ 47.60
[illegible]	5.60
[illegible]	60.48
	\$ 113.68
[illegible]	\$2750.00
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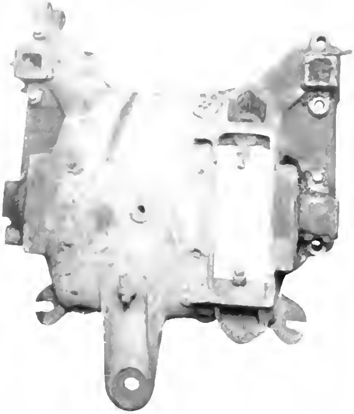

Fig. 2. Broken Cast Iron Motor Case Reclaimed by General Electric Constant Energy Welding Machine

While the need for such major welding repairs are of uncommon occurrence in any one plant, there are types of business in which the economical maintenance of equipment furnishes a continual opportunity for the inexpensive service of an arc welding outfit. One of these fields of application is in the maintenance of street railway equipment.

Arc Welding in Street Railway Repair Shops

Concerning the usefulness of electric arc welding machines in street railway shops, an executive recently said: "Electric welding has been rightly, though not completely, named the first aid to injured track and shop equipment." The following applications gathered from several railway shops confirm this opinion.

The most important welding operation in these shops is the building up of worn armature shafts, as shown in Fig. 1. There is no question as to the money saved by this operation, and where there are a number of shafts to be built up automatic arc welding is worthy of consideration.

When motors are subjected to severe vibration, considerable wear occurs to the threads in the gear casing bolt holes of the axle caps. Reclaiming these gear casings by arc welding takes but little time and the cost is extremely low. The operation requires a weld around the head of the bolt adjacent to the gear casing. The metal applied is of sufficient ductility to be filed and consequently could be dressed down if necessary. Slide bearing plates become badly worn but these can be built up to their original thickness by the use of an electric welder at a cost of approximately 10 cents each.

When a corner or lug breaks off a motor casing, as shown in Fig. 2, it can be quickly arc welded on again at small cost. Thus the casing can be kept from the scrap pile and be placed back in service. A number of railways are today using this operation with very successful results.

Due to constant vibration and heavy jarring, the bearing in the motor head often becomes badly worn, a wear of about $\frac{1}{64}$ inch requiring that the bearing head be taken out

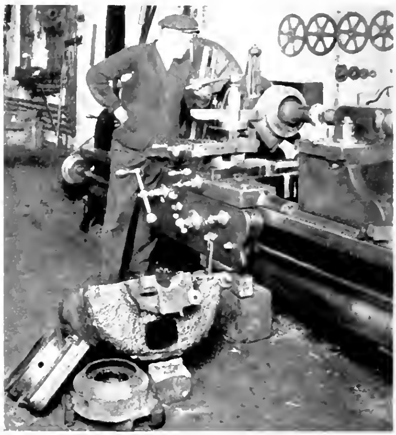

Fig. 3. Broken Cast Iron Motor Casing and Brake Housings Welded by General Electric Constant Energy Welding Machine (Case Broken in Twelve Pieces)

of service. Instead of the customary practice of using shims to obtain the proper fit, a light layer of metal deposited by the electric arc, and later machined to the desired fit, would make a much more serviceable repair.

Badly worn gear casings can be readily patched by the use of the electric welder; and broken teeth in motor gears can be easily and cheaply replaced.

Signal brackets, trolley bases, core heads on armatures, axle caps, brake-shoe heads, and half-ball hangers all can be repaired at a very low cost. Oftentimes no machining will be required after the welding operation is performed.

Side truck frames which often break in the pedestal can be successfully welded for one-quarter the cost of acetylene welding and in about one-third of the time, with the assurance of obtaining a high quality of work.

Fig. 4. Scrapped Cast Iron Motor Cases Being Reclaimed by General Electric Constant Energy Welding Machine

The saddle strap supports on the side frame of the car wear a groove on the frame which allows the strap to rub on the motor pot, thus causing a double source of trouble. With the use of the electric welder this worn condition on the frame can be readily corrected and the strap held firm.

A number of railways today are eliminating all the slid flat and flaked out places on cold rolled steel wheels and also are building up

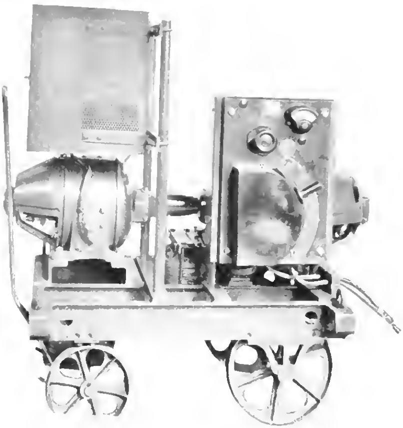

Fig. 5. Portable Single-operator Constant Energy Arc Welding Machine 60 20-volts 200-ampere

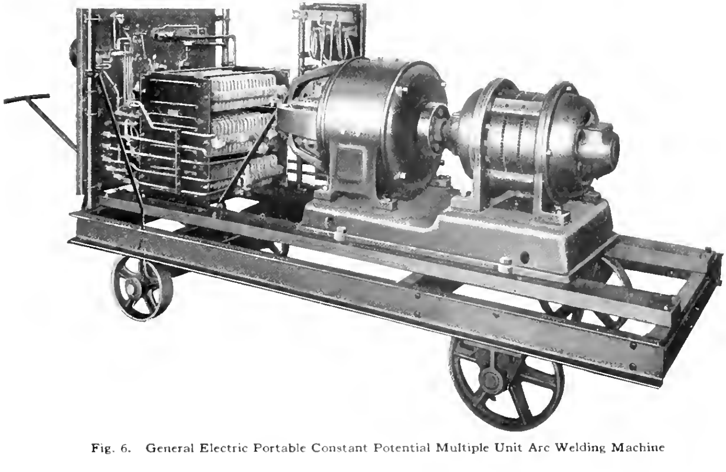

Fig. 6. General Electric Portable Constant Potential Multiple Unit Arc Welding Machine

[illegible] sharp. These [illegible] considerable saving, as [illegible] over a drop pit [illegible] disassembl[illegible] [illegible] for but a short [illegible] flanges the metal [illegible] same life as that [illegible] a saving does [illegible] enables the car [illegible] until such a time [illegible] the shop for other and [illegible]

[illegible] axle bearings, cup [illegible] gear and pinion seats, [illegible] motor casings, rail joints [illegible] third rails, and air reservoirs [illegible] successfully are welded. There is no doubt that there are a number of other applications that will develop from time to time in the field of arc welding electric railway equipment, but those mentioned will give some idea of the work now being successfully accomplished.

Three types of machines are used in connection with repair work of the foregoing character, each one being a desirable load for a central station. The low maintenance cost of any one of them makes it an attractive tool in any repair shop.

Fig. 5 shows a portable single-operator constant-energy equipment designed for both shop and street repairs.

Fig. 6 shows a constant-potential multiple-operator machine. This type of outfit, in addition to furnishing power for two or more welders, has also the advantage that it permits the use of the carbon arc which is often cheaper and more rapid than the metallic arc.

Fig. 7 shows a new type resistor arc welder. This equipment is used largely for rail bonding in which field it has proved very successful due to its ready portability.

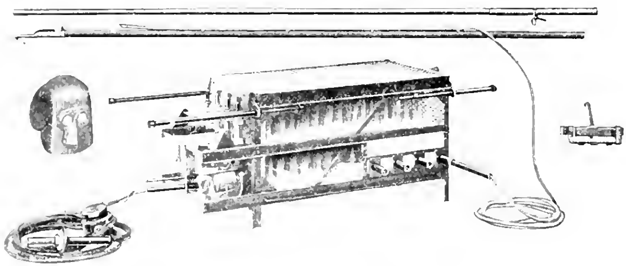

Fig. 7. 400 650-volt Resistor Arc Welder

Possible New Uses for Electric Power

By W. L. Merrill

Power and Mining Engineering Department, General Electric Company

W. L. Merrill

When considering the commercial uses of electric power that have come into existence in the past twenty years, it is hard to predict what new uses will be found in the future; in all probability they will in the main be extensions and modifications of present applications, rather than entirely new fields. Yet, it is absurd to predict that entirely new uses for power in large quantities will not be found, some of them perhaps equalling our present stable industries in power consumption. For example, who would have predicted ten years ago that the electric coal stripper, whose roadbed is a vein of coal say 6 feet thick, could economically be electrified; that it would be a paying proposition to run high tension lines and to purchase power from a remote central station to operate the strippers, when with the steam equipment all that is necessary is to shovel the coal from the roadbed into the boiler furnaces? Yet such is the case.

Many other similar applications have been developed for purely economical reasons and increase of production, such as burning coal in an industrial plant, generating steam to produce electric power which is transmitted to other parts of the plant to again generate steam in electric boilers for industrial uses, or converted to heat which is used directly, as in vulcanizing installations and similar processes.

When studying the means of devising new uses for electric power, consideration should be given to the economic question of improving the load factor of the central station, specially in those waterpower stations where, because of the storage facilities, water goes to waste over the dam during periods of light load. To correct this undesirable condition many companies grant an attractively low rate for energy delivered during these periods in order to increase the load factor, which is of course both logical and economical.

In some power plants during certain periods of the day or year when water (energy) is wasting over the dam, it would be logical for the central station to be modified in such a way as to become itself a manufacturing plant, utilizing its own surplus power. This project would have to be studied for each power station where surplus power could be used in the plant itself on an intermittent basis. Most of the work in the factory part of the plant could be done by the station operators without materially increasing the supervision or labor charges. This would mean that practically every dollar obtained for the product sold, after depreciation and maintenance and interest on investment, would be velvet. For example, it might be possible to install a number of small units for making nitric acid. The proceeds would probably be small as compared with the return from regular commercial operation, but would represent practically clear profit.

Various other commodities requiring a considerable amount of heat in their production might well be investigated with this purpose in mind; for instance, turpentine. Certain commercial glues from waste sulphite liquor are made by a simple process of evaporation. When direct current is available the manufacture of oxygen and hydrogen from water might be considered. Each locality, of course, has its own peculiar natural resources which would have to be studied, and a process decided upon for which the raw materials could be cheaply obtained and in which the cost of the finished product would be principally power or heat.

There is another field for the use of power which may in time be a factor in central station business, particularly in cities, which we will call "home manufacture." We know that in the past, particularly in European countries, practically all manufacture in some industries was performed by families and by individuals, the materials being left with them and the finished articles collected. In our own country this was, to a great extent, true of the clothing industry.

Modern methods of intensive production with automatic machinery have practically eliminated this system of manufacture. Yet, is it not logical to assume that, by taking advantage [illegible] machinery methods with certain [illegible], it is possible, for example, to [illegible] in the home, garage, or cellar, a [illegible] automatic machine for making [illegible]? The necessary attention [illegible] would be to put in a lar[illegible] in the morning, start the [illegible] and at night collect the day's product and place another reel of wire to feed the machine for the night run; the machine to be so safeguarded that in case of accident it would stop. Small nuts, bolts, screws, nails, and tacks, to say nothing of wood novelties turned from mandrels, would be possible products, which would find a market with the local hardware dealers.

Most of the automatic machinery used at the present time for making such things requires some attention from an operator. This is partly due to the excessive speed and high quantity of production expected from the machine. At a more moderate gait it seems thoroughly practical that machines could be made that run for say 12 hours without attention. The first cost of such machinery might be more expensive, but even so I believe there are many people who would be enthusiastic over the possibility of increasing their income by such a process. Several persons might combine their output of simple products, each making a part, to assemble a completed article.

A glance through the numerous chains of ten-cent stores will bring to mind many articles which could be manufactured in this way. This business would be considered by the central station perhaps in the class with its heating load and if required could be limited to night operation.

While we may not expect immediate results along the various lines mentioned above, yet it seems that here are possibilities which are well worth considering.

Possibilities of Material Handling Machinery Load for Central Stations

By J. A. Jackson

Power and Mining Engineering Department, General Electric Company

J. A. Jackson

In these days of high labor costs, supreme effort is being made in all lines of business to "do it mechanically," and in over 90 per cent of the cases this means "do it electrically." Much has been written since the war regarding the cost of handling materials in terminals, warehouses, and factories, and this publicity has undoubtedly done a great deal toward focussing the attention of managing officials on this problem and causing them to investigate cheaper ways of moving their material. Thus quite an impetus has been given to the sale of mechanical devices to perform this work, but even so the surface has only just been scratched. The campaign of education and enlightenment in the economies resulting from the intelligent use of freight handling machinery goes on unabated and the sales curve of such devices continues to slope upward. The public, however, has not yet been aroused to the extent of realizing how vitally it should be interested in this question and the one thing which will probably be the greatest factor in bringing the matter to their attention will be the proposed compulsory segregation of freight charges by the Interstate Commerce Commission into terminal charges and line haul charges on steamship lines and railroads. Such a segregation, if adopted, will show up the comparative costs of terminal handling, as against line haul costs and the publicity which will undoubtedly be given to the figures will create a firm national demand for more efficient methods of handling materials. Railroad and water transportation lines realize this situation and are already taking such steps as their finances will permit to remedy the situation so as to make the best possible showing if the foregoing segregation goes into effect.

This is a situation in which the central station is, or should be, deeply interested since it opens up wonderful possibilities for an increased load. A few figures and statistics will give a clear idea as to the potential load obtainable from railroad and steamship terminals if completely equipped with machinery and modern lighting.

The export tonnage of the United States in 1919 amounted to 74,000,000 tons, and the import tonnage to 33,000,000 tons, to which must be added the coastwise tonnage on which exact figures are not available but it probably amounts to 20,000,000 tons per annum. The sum of these three, 127,000,000 tons, gives approximately the freight which passed through our marine terminals for that year. Calculations of current consumption when loading and unloading on various cycles and by different methods and equipment indicate that a current consumption of 200 watt-hours per ton is a fair average value when using cranes or winches equipped with modern series or compound-wound motors and dynamic braking control. This value has been checked quite closely by actual tests. This current consumption covers only the transfer of the freight between the hold and the pier at the ship's side. Assuming that only one-half this tonnage is handled by central station power and the other half is hoisted by ship's winches, we find a power consumption of 12,700,000 kw-hr. per year for loading and unloading between ship and pier.

Since the freight must be transferred horizontally between the ship's side and some point on the pier, another opportunity is presented for the use of power driven machinery. Tractors with trailers and industrial trucks, operated from storage batteries, are admirably adapted for this service and are coming into use very rapidly. Calculations indicate that one ton can be hauled 100 feet in these devices and the empty vehicle returned to the starting point (200 ft. total travel) for an expenditure of about 50 watt-hours per ton, allowing for all losses from the motor pinion to the incoming power supply at the battery charging room. Portable and stationary conveyors, monorails, ramps, industrial railways, truck cranes, etc., all find a place, depending on conditions, in the horizontal transference of freight, and while figures are not available for the power consumption per ton handled it will probably average somewhere near 50 watt-hours per ton as on tractors and trucks. Probably 80 per cent of the total tonnage can be more economically transferred by power driven equipment than by hand trucks, and on this assumption the yearly power consumption would be 5,000,000 kw-hr. for an average movement of 100 feet inside the pier sheds.

A certain percentage of the freight is again rehandled between the pier sheds and the supporting warehouses involving a horizontal transfer which will, no doubt, average at least 200 feet (100 feet round trip) horizontal movement, and usually a vertical movement which will average at least 30 feet. The horizontal transfer can be handled by the same equipment as is used on the pier and at the same power consumption per ton. The vertical movement in this case would be made by freight elevators which, in a modern warehouse, would take from four to six loaded trailers on its platform at once taking them up and returning with empties, or vice versa. Such an elevator would handle a ton over a 30-foot lift for about 150 watt-hours power consumption. Assuming that only 50 per cent of the total import, export, and coastwise tonnage goes through storage warehouses, a power consumption of 12,700,000 kw-hr. would have been required in 1919 for the horizontal and vertical movements between piers and warehouses. Since warehouse facilities at many of our ports are admittedly inadequate, there is an enormous potential field for the sale of power to improve the facilities of existing buildings and in making all new ones approach perfection from the standpoint of efficiency. Warehouses also offer a large field for the use of electrically driven piling machines, portable conveyors, barrel and bag elevators, refrigerating plants, cleaning systems, repair and recoopering shops, etc., the power consumption of which is difficult to estimate but which must run into large figures in a year's time.

The correct lighting of marine terminals for efficient work offers enormous possibilities. An investigation of 58 large piers in one of our ports showed that only 6.2 per cent had good illumination. Ample illumination increases the speed of trucking, facilitates the reading of marks, reduces theft and spoilage, and cuts down the number of mis-sent shipments. On piers handling general freight, adequate lighting requires about 1/4 watt per square foot of floor area. Thus a pier 1000 by 150 requires 37.5 kw., and if the lights are used an average of four hours a night for 300 days per year the yearly consumption is 45,000 kw-hr. per year. Assuming that for all the ports in the United States there is the equivalent of 1000 such piers to be lighted, the consumption of 45,000,000 kw-hr. per annum would be required. For warehouses the average illumination need not be so high and a figure of .15 to 0.2 watts per square foot is advisable.

[illegible] railroads, the tonnage [illegible] United States in 1919 [illegible] and a large percentage [illegible] profitably handled by [illegible] than by the hand methods [illegible] Of course, a large percentage [illegible] bulk freight which is already [illegible] efficiently by mechanical means. [illegible] is miscellaneous or pack- [illegible] largely handled by manual [illegible] such machinery is readily [illegible] well adapted for doing the [illegible] Naturally there are many terminals [illegible] are too small to justify power driven [illegible] equipment, but even with the tonnage handled in them omitted there still leaves a tremendous field for the use of electrically driven machinery.

Tractors with trailers and industrial trucks are well adapted for handling package freight at railway terminals, and they should form a very desirable load for central stations as arrangements can, no doubt, often be made whereby most of the charging can be done during the light load hours, thus helping the load-factor. There are many railroad terminals where, due to local conditions and the particular kind of freight handled, other types of power driven equipment can be profitably used.

The problem of standardized containers for use on freight cars is being very thoroughly studied by the railroads, some of them having sample cars and equipment in use. There is no doubt in the minds of those who have made a complete study of the problem that standardized containers must be generally adopted sooner or later, but much more educational work and many more successful demonstrations must be made before they are generally used. Their adoption will also require extensive financing, which will take time. This financing is not alone for the containers but for the cranes, hoists, monorails, trucks, etc., which will be absolutely necessary for handling them, practically all of which will be electrically driven. Thus they will offer an opportunity for the sale of hundreds of thousands of kilowatt-hours per year, for which reason it would be a good policy for the central station men at large to get squarely behind any propaganda put forth in favor of standardized containers. By taking such a position they will not only be furthering their own interests but will be assisting a movement which will, unquestionably, effect enormous economies in the cost of transportation.

The handling of material in industrial plants during the process of manufacture has come in for scientific study only in recent years, and an investigation made by the *Literary Digest* within the last two years disclosed the fact that only 5 per cent of the plants in the United States use power driven material handling machinery extensively, and only 35 per cent of the manufacturers are at all familiar with this class of machinery. The investigation showed further that there was a field for the sale of over 200,000 units of material handling machinery such as trucks, tractors, conveyors, winches, cranes, locomotives, etc., and that it is reasonable to expect that they will consume over 500,000,000 kw.-hr. of power per year.

Table I shows the probable increase in annual power consumption if all terminals, warehouses, and industrial plants in the United States were equipped with efficient material handling machinery. On the basis of 3000 working hours per year, this would call for the continuous expenditure of 208,400 kw.

TABLE I

PROBABLE INCREASE IN POWER CONSUMPTION BY THE ADOPTION OF ELECTRICAL MATERIAL HANDLING MACHINERY IN ALL INDUSTRIAL PLANTS, TERMINALS, ETC. IN THE U. S.

Where Used	Kw-hr. Per Year
Between ship and pier	12,700,000
Between ship side and pile	5,000,000
Between pier and warehouse	12,700,000
Miscellaneous warehouse machinery	10,000,000
Lighting of terminals and warehouses	60,000,000
Railroad terminals	25,000,000
Industrial plants	500,000,000
Total	625,400,000

It is believed that there is no other field which offers such possibilities for development as the material handling field, but many factors enter which make it one that will require much constructive work. Some of these are the scarcity of reliable actual data to show economics gained, variety of the problems to be met, unadaptability of existing structures and plant layouts to the introduction of suitable material handling machinery, lack of knowledge of the various types of available machinery, little or no demand from the public for improved methods due to lack of knowledge regarding the possibilities of price reductions by efficient handling. These problems are those of the central station power solicitor, and his success depends largely on his knowledge of how to overcome them most effectively.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Compensating Windings

Operation of Direct-Current Machinery with Compensating Windings. Phillips, H. M.
Power, Apr. 19, 1921; v. 53, pp. 620-624.
(Illustrated paper on the practical features.)

Electric Currents, Alternating

Study of a General Method of Construction of A. C. Circle Diagrams. Le Cocq, R. (In French.)
Revue Gén. de l'Elec., Apr. 9, 1921; v. 9, pp. 483-492.
(Mathematical.)

Electric Locomotives

New Theories of Vibrations in Locomotives Provided with the Crank Drive. (In German.)
Elek. Zeit., Feb. 3, 1921; v. 42, pp. 103-107
(Primarily a review of recent literature. Serial.)

Swiss Electric Locomotive Progress.
Elec. Rwy. Jour., Apr. 16, 1921; v. 57, pp. 725-727.
(Illustrated description of B B C and Oerlikon locomotives.)

Electric Motors, Induction

Circle Diagram of Polyphase Induction Motors. Kostko, J. K.
A. I. E. E. Jour., Apr., 1921; v. 40, pp. 326-332.
(Mathematical.)

Comparative Study of the Diagrams of Polyphase Induction Motors. Le Monnier, J. and Décotte, R. (In French.)
Revue Gén. de l'Elec., Apr. 2, 1921; v. 9, pp. 463-470.
(Theoretical article in which test results are shown.)

On the Design of Split Phase Motors. Binney, E. A.
Elec'n (Lond.), Mar. 18, 1921; v. 86, pp. 322-325.

Electric Motors, Synchronous

Synchronous Motors and Their Industrial Application. Mortensen, S. H.
Elec. Rev. (Chgo.), Apr. 16, 1921; v. 78, pp. 613-616.
(Practical features of operation. Serial.)

Electric Transmission Lines

Calculation of Voltage Drop in Alternating-Current Transmission Lines. Huldschiner, G. (In German.)
Elek. Zeit., Jan. 27, 1921; v. 42, pp. 73-78
(Mathematical treatment with special reference to line capacity and to improvements possible with conductors of variable cross-section.)

Construction and Cost Features of Rural Lines. Neff, G. C.
Elec. Rev. (Chgo.), Apr. 2, 1921; v. 78, pp. 529-535.
(Includes considerable statistical data.)

Damping of Periodically Loaded Lines. Velander, Edy. (In Swedish.)
Tekn. Tidskr. (*Elektr.*), Jan. 5, 1921; v. 51, pp. 12-15.
(Mathematical treatise on transmission line phenomena. Serial.)

Mechanical Details of Construction of High-Tension Over-Head Lines. Kyser, Herbert. (In German.)
Siemens-Zeit., Jan., 1921; v. 1, pp. 2-6.
(With numerous illustrations. Serial.)

Electric Welding

Present Day Industrial Applications of Electric Welding.
Elec. Rev., Apr., 1921; v. 29, pp. 250-259.
(Describes welding equipment and operations, and includes a tabulation showing the many applications.)

Frequency Changers

Static Frequency Doublers. Peters, J. F.
Elec. Jour., Apr., 1921; v. 18, pp. 122-123.
(Short article by a Westinghouse engineer.)

Gears, Reduction

Mechanical Gears, of Double Reduction, for Merchant Ships. Walker, R. J. and Cook, S. S.
Engr. (Lond.), Mar. 25, 1921; v. 131, pp. 327-328.
(Technical paper showing test results. Also in *Engng.* (Lond.), Mar. 25, 1921, pp. 369-370.)

High Frequency

Why High Frequency for Radiation? Slepian, J.
Elec. Jour., Apr., 1921; v. 18, pp. 129-131.

Inductive Interference

Electrical Interference by Propulsion Circuits.
Rwy. Elec. Engr., Apr., 1921; v. 12, pp. 157-162.
(Abstract from report presented to American Railway Engineering Association.)

Insulating Oils

Deleterious Effect of Fibres on the Electric Insulating Power of Oils. McLaughlin, Thomas A.
Elec'n (Lond.), Mar. 18, 1921; v. 86, pp. 325-327.

Insulation

Investigation of the Heat Conductivity of Insulating Materials Used in the Construction of Turbo-Alternators. Janet, P. (In French.)
Revue Gén. de l'Elec., Mar. 19, 1921; v. 9, pp. 393-402.
(Presents both theory and tests results.)

Metal of [illegible] Magnesium. Backer, C[illegible] In Norwegian.
Tekn. Uke., M[illegible] 1921; [illegible] 68, pp. 107-109.
Devoted [illegible] of magnesium [illegible] and of its oxide as [illegible] See also "Magnesium [illegible] in *Electrical In[illegible]*, Mar. 30, 1921, p. 395.

[illegible] of High-Voltage Alternating-Current Windings. Zederbohm, W. In German.
[illegible]mens Zeit., Jan., 1921; v. 1, pp. 15-22.
Method used by the Siemens Company. Many illustrations. Serial.

Power Plants, Electric

Colfax Power Station of the Duquesne Light Company, Pittsburgh. Gadusha, D. L. and Clarke, C. W. E.
A. I. E. E. Jour., Apr., 1921; v. 40, pp. 281-294.
Well-illustrated, lengthy description. Same, condensed, in *Elec. Wld.*, Apr. 2, 1921, pp. 753-760.

Protective Devices

General Conditions for Proper Functioning of Grounded Protective Devices. Willheim, Raoul. In German.
Elek. und Masch., Mar. 20, 1921; v. 39, pp. 137-140.
Mathematical discussion for a case of n-phases. Serial.

Radio Stations

Paris Radio Central.
Radio Rev., Mar., 1921; v. 2, pp. 125-133.
Illustrated description.

Railroads, Electric

Operating Curves and Safety of the Various Methods of Regenerative Braking Used on Electric Railroads. Kummer, Dr. W. (In German.)
Schweiz. Bau., Mar. 26, 1921; v. 77, pp. 139-142.
Includes diagrams and curves. Serial.

Resistance, Electric

Connection of Regulating Resistances Resulting in Economy of Resistance Material. Richter, Rudolf. In German.
Elek. Zeit., Mar. 10, 1921; v. 42, pp. 217-222.
Mathematical discussion of a new parallel-series connection scheme for which many advantages are claimed. Diagrams.

Steam Boilers, Electric

Electrically Heated Steam Boiler in Sweden. In German.
Elek. Zeit., Jan. 27, 1921; v. 42, pp. 78-79.
Details of an installation in a paper mill, with cost data.

Steam Turbines

Some Recent Developments in Large Steam Turbine Practice. Baumann, K.
Engng. (Lond.), Apr. 8, 1921; v. 111, pp. 435-438.
Interesting paper before I. E. E. Includes considerable statistical and bibliographical material. Serial.

Strength of Materials

Failure of Metals Under Internal and Prolonged Stress.
Engr. (Lond.), Apr. 8, 1921; v. 131 pp. 371-372.
(Abstract of a symposium delivered before a joint meeting of seven British engineering societies. Same in *Engng.* (Lond.), Apr. 8, 1921; pp. 418-421, 435.)

Substations, Automatic

Automatic Substation in Switzerland.
Elec. Rwy. Jour., Apr. 9, 1921; v. 57, pp. 681-683.
(Illustrated description of a B B C installation at Riehen near Basel, Switzerland.)

Vacuum Tubes

Specifications and Characteristics of Moorhead Vacuum Valves. Moorhead, O. B. and Lange, E. C.
Inst. Radio Engrs. Proc., Apr., 1921; v. 9, pp. 95-129.

Water Turbines

Kaplan Turbine and Its Economic Significance. (In German.)
Trua, Mar. 1, 1921; v. 2, pp. 193-196.
(Illustrated description giving results of tests and recent applications.) Clipping No.

X-Rays

X-Rays and Their Industrial Applications.
Engng. (Lond.), Apr. 8, 1921; v. 111, pp. 412-415.
(Abstract of three lectures by G. W. C. Kaye. Considers the Coolidge tube.)

NEW BOOKS

Armature Winding. Moreton, David P. 196 pp., 1920, Chicago, American Technical Society.

Powdered Coal as a Fuel. Ed. 2, rev. Herington, C. F. 338 pp., 1920, N. Y., D. Van Nostrand Company.

Cost Accounting to Aid Production. Harrison, G. Charter. 234 pp., 1921, N. Y., The Engineering Magazine Company.

Small Motors, Transformers, Electromagnets. Stoller, H. M. and others. 320 pp., 1921, Chicago, American Technical Society.

Practice of Lubrication. Thomsen T. C. 607 pp., 1920, N. Y., McGraw-Hill Book Company, Inc.

Pumping by Compressed Air. Ed. 2, rev. Ivens, Edmund M. 266 pp., 1920, N. Y., John Wiley & Sons, Inc.

Wireless Experimenter's Manual. Bucher, Elmer E. 341 pp., 1920, N. Y., Wireless Press, Inc.

Service at Cost Plans. Clark, Harlow C. 315 pp., 1920, N. Y., American Electric Railway Association.

Relativity: the Special and General Theory. Einstein, Albert. 168 pp., 1920, N. Y., Henry Holt and Company.

Automatic Telephone Practice. Ed. 3. Hershey, Harry E. 221 pp., 1920, Chicago, Harry E. Hershey.

Ventilation Hand Book. Hubbard, Charles L. 231 pp., 1920, N. Y., The Sheet Metal Publication Company.

Illumination Design Data. Anderson, Earl A. 32 pp., 1921, Cleveland, National Lamp Works of General Electric Co. Bulletin 41, Engineering Dept.

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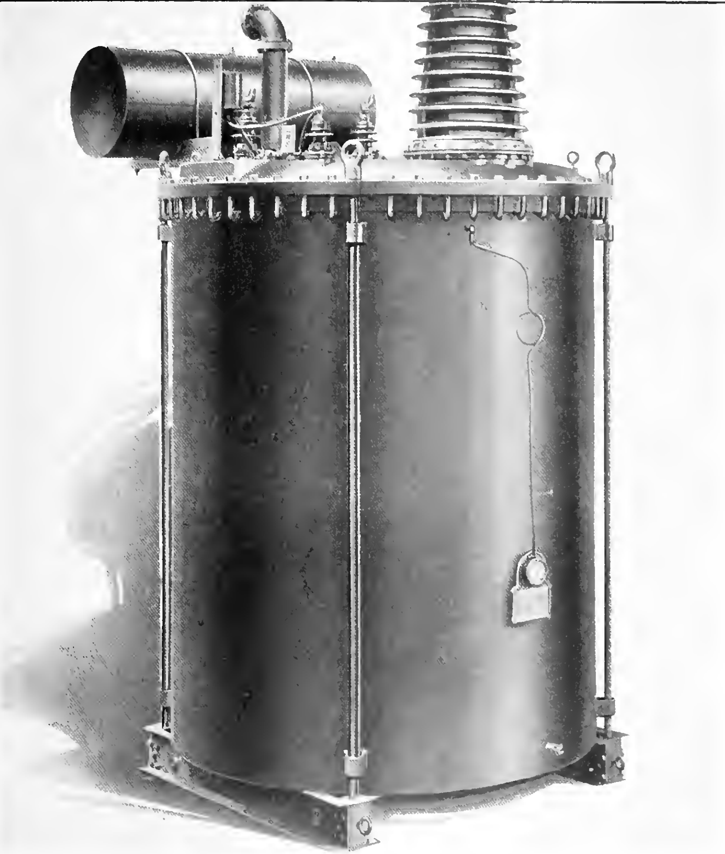

THE FIRST 220,000-VOLT TRANSFORMER SUPPLIED BY ANY MANUFACTURER FOR POWER TRANSMISSION SERVICE. PHOTOGRAPHS OF THE INTERIOR OF THIS TRANSFORMER ARE SHOWN AS THE FRONTISPIECE OF THIS ISSUE

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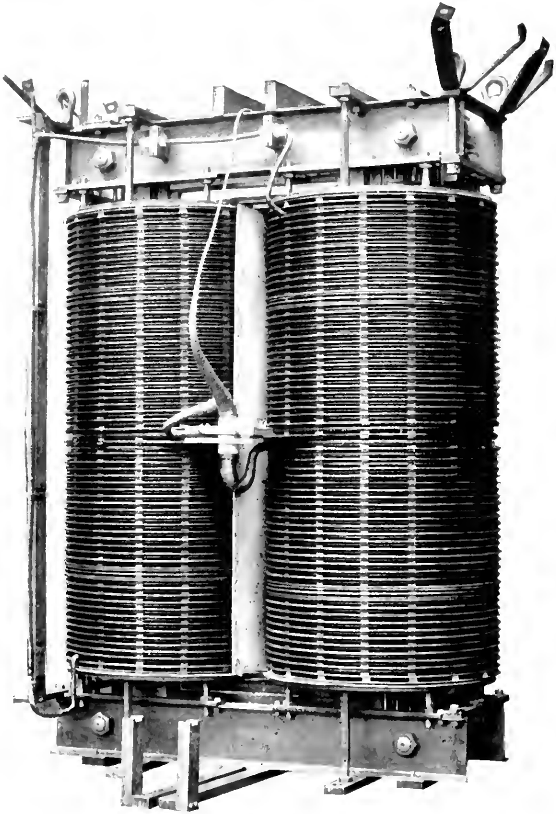
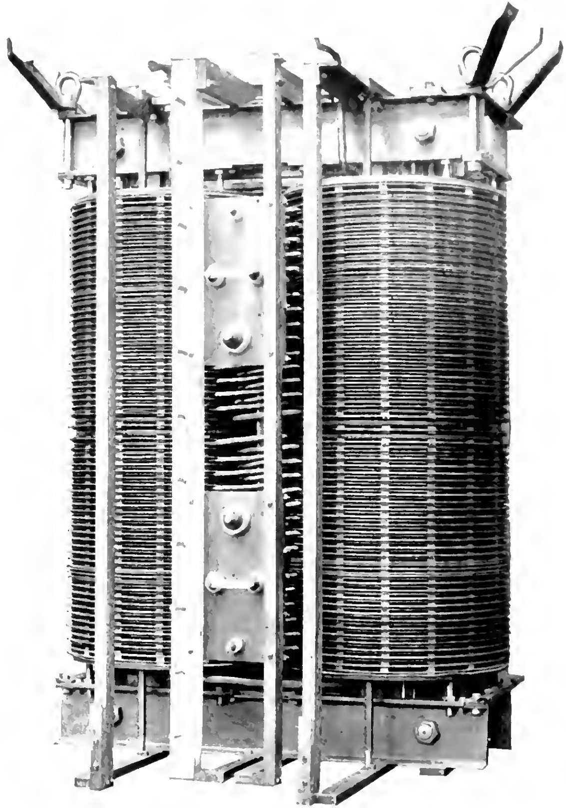




Views of 220,000 volt, 8,333-kv-a. Transformer, four of which were recently manufactured for the Southern California Edison Company by the Pittsfield Works of the General Electric Company. These are the first transformers to be supplied by any manufacturer for regular commercial service at 220-kv. They embody the circular-coil construction, which long service has shown to be superior to any other form of coil and which the General Electric Company has strongly advocated for large high-voltage transformers. These transformers were described in an article by Mr. Clinton Jones in our May issue.

GENERAL ELECTRIC REVIEW

AUTOMATIC SUBSTATIONS

We publish in this issue a group of articles on automatic substations and included in these are considerable data showing their efficiency. These data are derived from very comprehensive tests, the most complete, perhaps, that have ever been made in connection with automatic substation equipment on a large scale when operating in actual service. The results of these tests are highly satisfactory and we are glad to give them to our readers, some of whom at least, must be contemplating means and ways of reducing operating costs to meet the present severe economic conditions imposed on all operating engineers.

Mr. Chas. H. Jones in his article, dealing with the results accomplished on the Chicago, North Shore & Milwaukee Railroad, shows that a saving has been made of $3,804 per substation per year, or a total for the North Shore Line of $41,351 per year. This is a considerable item.

Mr. S. E. Johnson concludes his article dealing with his experience with the automatic substations on the Aurora, Elgin & Chicago Railroad with the statement, "Automatic substations are now an accomplishment and no longer an experiment. They are truly reliable, more so in fact than manually controlled stations, and they will show great economy right from the start."

We interpret the concluding remarks of both of our authors as recording another victory for the engineer whose work has been so aptly defined as "doing for one dollar what a fool cannot do for two."

The functions of a substation attendant were always unsatisfactory, in fact, he might be regarded in somewhat the same light as we regard a life belt. He very seldom has any useful function to perform, but when he has it is urgent and when things go wrong it requires a man of considerable experience to know just how to do the right thing at the right time. This is no reflection on the ability of the substation attendant, but as things work out in practice there is not enough work of importance to warrant paying an experienced man to become a substation attendant, and the type of man employed in such work could therefore seldom be relied on to always do the right thing promptly. There was always the fear that he might do the wrong thing in case of an emergency. The substitution of machines for men, wherever this is possible, must in an increasing degree continue to be one of the chief aims of our engineers, especially in such cases where the machine can be developed to a point where there is no fear of mistakes in an emergency. The articles under consideration show in a convincing way that the automatic apparatus as at present developed for substation operation is both reliable and economical.

THE PAULISTA ELECTRIFICATION

Mr. Bearce's article in this issue describes the substation equipment and the material for the overhead line and transmission system as well as the electric locomotives for one of the principal railways of Brazil. This electrification has been undertaken to meet the changed economic conditions that so many countries are facing today. The use of coal having become so costly, wood was substituted as a source of fuel, but, although Brazil has ample wood, the labor involved in cutting and carting is great and no one could contemplate the continued use of such large quantities of so valuable a national resource without concern. The initial electrification calls for equipment for 28 miles of double track, or a total trackage on a single track basis, including sidings, etc., of 76 miles. This is likely to be extended in the near future.

Brazil is fortunate in being able to take advantage of our experience in this country with heavy electric traction and it is interesting to note that 3000-volt, direct-current equipment has been adopted and that in design, the locomotives closely follow those that have given such unqualified success on the Chicago, Milwaukee & St. Paul Railway. The development of Brazil's hydro-electric resources for the electrical operation of her railways is likely to stimulate the growth of her other industries and lead to a great increase in her national wealth

SCIENTIFIC RESEARCH IS TO THE PUBLIC INTEREST

Excerpt from Presidential Address by A. W. Berresford at the Annual Convention of the American Institute of Electrical Engineers, Salt Lake City, June 21-24, 1921

The appreciation of the ultimate dependence of industry on science and the consequent vital importance of research is of too recent birth to have attained general realization. The statement is accepted as a matter of course, but it has not come to be an actual, living, daily reality in the minds and life of most of us. That it will ultimately be so recognized is certain, and possibly in the near future. This being the case, how are we providing for it?

The larger corporations are maintaining research laboratories—have been forced to do so by the demands of the industry—in which the bulk of this work has been directed toward the solution of specific problems, the results of which are generally conceived to be for the benefit of the corporation individually, and in part may be so initially.

The universities are carrying on research work in their laboratories to an extent determined by their financial resources and the initiative of their personnel; mostly of abstract nature, directed to the solution of general problems, chosen largely, and sometimes I think mistakenly, for the absence of applicational content.

The Bureau of Standards, under government auspices, and in the interest of the country's industry, is performing work of both kinds.

There are certain privately operated laboratories whose services may be employed by the industry in general for the solution of specific problems.

To determine how the work as a whole should be correlated to secure the maximum progress requires an understanding of the conditions.

The first conception which it seems necessary to establish is that all research is in the public interest—whether applied or abstract, and irrespective of whether its immediate object is the specific advantage of the concern or person undertaking it, or simply the increasing of the sum of human knowledge.

No one will question that abstract research, forming, as it frequently does, the foundation of important industrial advance, and given to the world without restriction, is definitely in the public interest. There may be those who question the content of what may be termed "practical applications" and who would limit investigation to the more promising possibilities, but the past gives ample warrant for future expectation, and no man can say in advance where value may be found. Much that today seems of no practical value may simply be awaiting the key discovery which will be found by no process other than that of this constant search for fundamental truth.

The misunderstanding seems to lie in the so-called "applied or applicational research," usually directed toward a specific problem, the solution of which becomes, under our patent system, the exclusive property of the initiator and a consequent source of gain. Is not this as it should be? Without this incentive no corporation could justify to its stockholders the necessary expenditure, and but few individuals would possess the necessary resources; for not every problem is solved and many months are spent in work that brings no fruition. Moreover, the period of exclusive use is limited and but short compared with the time during which the solution may ultimately be freely used by all. Again, the public as a whole usually reaps the benefit of the solution during this period of exclusive use and is advantaged in such degree as to make the reward to the owner small in comparison.

It becomes clear, therefore, that *all* research is in the public interest, and that from the public viewpoint the sole difference in desirability between abstract and applied research is one of degree and not of fact; that the important point is increased research activity irrespective of where or by what means it is carried on.

In feeling that industry must supply the driving force, I am not setting the hope of gain as a greater impulse than the search for truth, but means must be supplied, and to industry, the producer, we naturally turn.

Fundamental research, however, must be provided for. The search for truth will supply the incentive, but not the means. Universities will do what their poverty permits, but it is not sufficient. Industry must increase the possibilities. An incentive must be offered to induce temperamentally fitted men to undertake this career and to become largely qualified, else industry will go begging for the men it will need in increasing quantity for its applied research. Men now exist, in reasonable number, whose devotion and achievement in this field are an inspiration and an example for emulation among their co-workers which is of far-reaching effect. Given even a minimum of encouragement the future will continue to evolve them, and once in a generation or so a genius.

Results of Automatic Substation Operation on the Chicago, North Shore & Milwaukee Railroad

By Chas. H. Jones

Electrical Engineer, Chicago, North Shore & Milwaukee Railroad

The service performed by the Chicago, North Shore & Milwaukee R. R. is of a heavy interurban character comparable to many interurban steam lines. The demands on the substations are most exacting and the unqualified success of the six automatic substations is significant. The thorough going methods employed by Mr. Jones in the inspection and maintenance of these substations are most instructive. The article (which was delivered as a paper by the author last March before a Joint Convention of the Illinois Gas, State Electric, and Electric Railways Associations) outlines the system of inspection and includes general statistics as to the amount of traffic and power consumption as well as data on the operation of the automatic equipments.—Editor.

In order that a better knowledge may be obtained of the conditions under which automatic substations have been given a general try-out on the Chicago, North Shore & Milwaukee R. R., it is desirable first to review briefly the general history of the line.

The road is a high-speed interurban line between Chicago and Milwaukee, following the route shown in Fig. 1. Its Chicago entrance is over the elevated lines and its Milwaukee entrance over the city streets. The territory in between is well built up with a series of towns of a general resident and business character. As the southern end of the line is in almost exclusive residential territory and as the line is built through practically the center of these suburban towns, the speed of operation is restricted and requires frequent stops and slow-downs. The northern end of the line is built on the outskirts of the combination business and resident towns of Waukegan, Kenosha, and Racine. In between these points the line runs through open country in practically a straight line which makes operation possible at speeds of 65 to 70 miles per hour.

The steam road competition between the terminals is very keen so that nothing but the best of service in time, comfort, and safety is necessary to get a fair share of the possible business. In line with this service, dining cars are operated morning, noon, and night. To meet competition it was necessary to purchase the most modern type of car equipment. This now consists of 30 all-steel motor cars weighing approximately 47 tons each and equipped with four 140-h.p. motors. A three-car limited train of these cars is shown in Fig. 2. In addition there are 15 all-steel trailer cars weighing approximately 40 tons each. There are also a large number of wooden interurban motor and trailer cars used for local and express business.

In order to make the best use of a heavy investment in right-of-way, track, overhead, and power equipment and to furnish a fast freight service to the thriving communities along the line, it was decided to institute a merchandise despatch line for which purpose 12 new wooden cars of a very pleasing appearance were purchased. Some of these cars

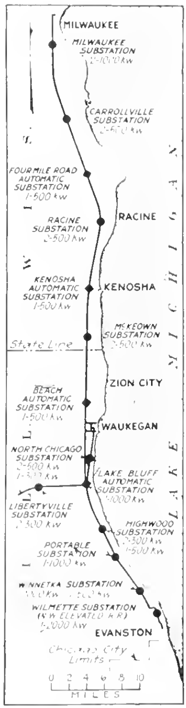


Fig. 1. Map Showing Route and Location of Substations on the C. N. S. & M. R. R. System

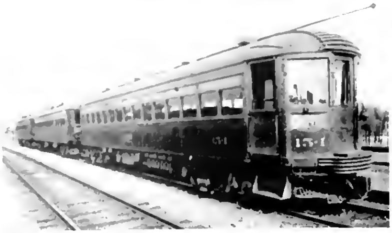


Fig. 2 Three car Limited Train on the North Shore Road

Fig. 3. Some of the Merchandise Despatch Cars of the North Shore Road

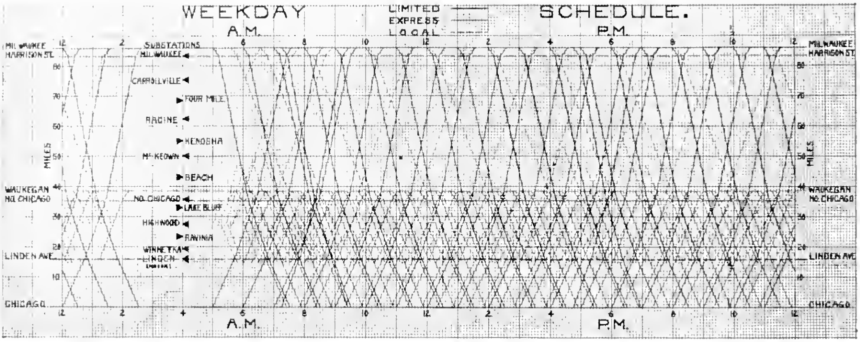


Fig 4a. Graphic Weekday Schedule of Limited, Express, and Local Trains Between Chicago and Milwaukee

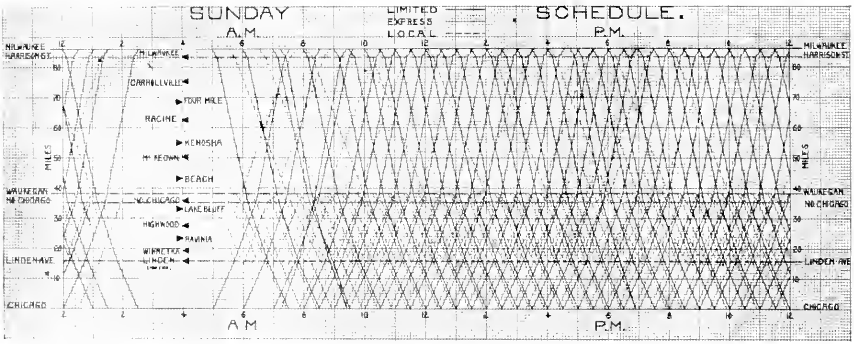


Fig 4b. Graphic Sunday Schedule, Showing Volume of Service Furnished

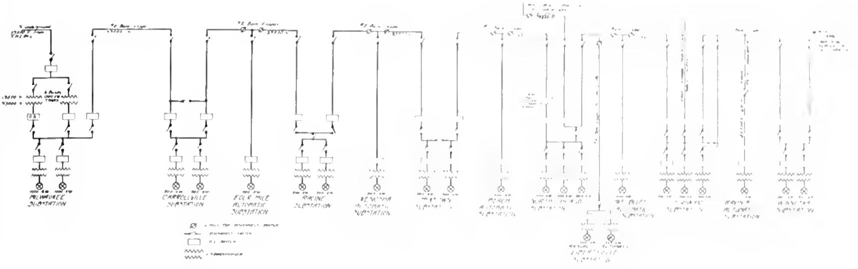


Fig. 5. Diagram of the High-tension Distribution and Substation Connections

are illustrated in Fig. 3. These, together with a number of other cars, are used in giving an overnight merchandise despatch service between Chicago and Milwaukee.

With the present rolling stock, track, and power conditions, a schedule of two hours and thirty-five minutes is maintained on limited service between terminals and two non-stop trains in each direction daily make the run in two hours and fifteen minutes. In addition to this service an express and local service is furnished to various points on the line. The best method of describing the volume of service furnished is by the graphic schedule given in Figs. 4a and 4b.

As an indication of what results have been obtained on account of the service furnished, Table I shows the growth of travel and service from 1915. During the period of the war, travel was very heavy between Chicago and the Naval Training Station at Lake Bluff, which travel diminished as the size of the force at the station was reduced after the war, but the general growth of travel along the line, and especially between the two terminals, was more than ample to offset the drop off at the Naval Station.

In order to handle this large increase in business it was necessary to make extensive additions to the power system as it was in 1916. At that time the system was adequate to handle single-car operation, but with the heavy train operation required, the power system was inadequate. In order to maintain a high schedule speed, it was necessary to have a very high gear ratio which on the steel equipment purchased in 1916 was two-to-one. At that time there was on the system 9,500 kw. in synchronous converter and 3,000 kw. in step-up transformer capacity and now there is 11,500 kw. in synchronous converter and 4,500 kw. in step-up transformer capacity. This amounts to an increase of 52.6 per cent in converter capacity and 50 per cent increase in transformer capacity, with which equipment it is possible to handle approximately a 100 per cent increase in the alternating-current kilowatt-hours purchased. This is due to the fact that the additional equipment was interspaced between the original substations, thereby reducing the amount of line loss and making available additional power for effective traction purposes. As shown in Table I the energy consumption per car-mile was reduced from 5.78 to 4.31. This reduction is due to a general improvement in operating efficiency, one of the factors of which is the interspaced substations, but the exact amount for which they are responsible cannot be determined.

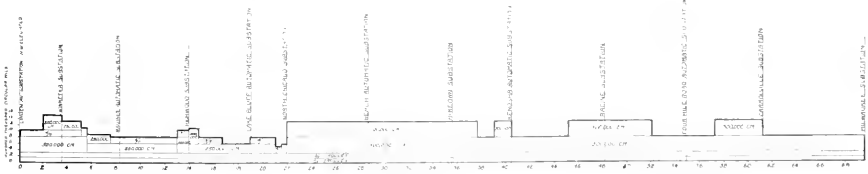


Fig. 6. Diagram of the Feeder Capacity of the 600-volt Direct-current Distribution System

Fig. 7 Exterior View of the Lake Bluff Automatic Substation

Fig. 8 Interior View of the Lake Bluff Automatic Substation

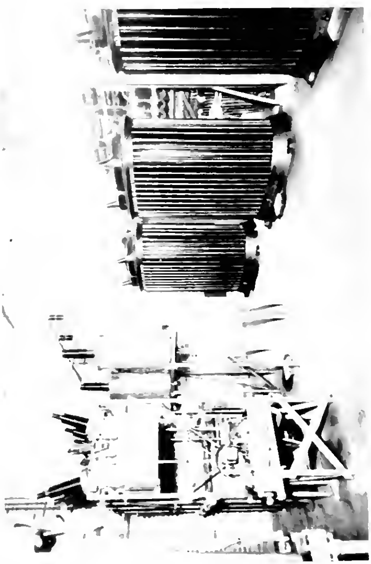


Fig. 9. Interior of the Kenosha Automatic Substation, Showing 33,000 volt Power Transformers, Oil Circuit Breakers and Mechanism

Fig. 10. Interior of the Kenosha Automatic Substation, Showing Control Board and Load-limiting Resistors

Before this method of power development was entered into, consideration was given to raising the line voltage on part of the system to 1200 volts, but this proposition was abandoned on account of the excessive cost of changing the car control equipment and old motor equipment. Consideration was also given to additional feeder copper but this was also abandoned on account of the heavy cost. It would cost approximately $650,000 to accomplish the same voltage betterment as was accomplished with interspaced substations, and fundamentally this is the wrong method of correction to apply in a power distribution system. In order that a clear understanding of the connection scheme and substation switching combination may be had, a map of the high-tension system and substations is shown in Fig. 5. A feeder capacity diagram is shown in Fig. 6, but no changes have been made in this since before 1916.

Power is purchased from two sources which at times makes it necessary to do considerable high-tension switching from one power source to the other so that the automatic stations have had rather severe operating conditions.

Before going ahead with the installation of automatic substations a careful study was made of other installations at that time and thus the best design of building and layout was obtained. Although the station erection has extended over almost four years and other installations have been carefully investigated, it has not been seen advisable to change the design of the building or layout on account of these investigations or on account of defects showing up in our own experience.

The buildings are of simple design and are made of brick, steel, and concrete with ventilation supplied by louvers at the floor line and Burt ventilators in the roof, the general dimensions being 38 ft. long, 32 ft. wide, and 22 ft. maximum inside height. The general construction and interior arrangement are shown in Figs. 7, 8, 9 and 10. A more detailed description has been published in the *Electric Railway Journal* of January 11, 1919.

The layout of apparatus within the building is such as to provide the maximum convenience and safety for work on and around the equipment. All high-tension connections are raised ten feet above the floor so that it is impossible to come in accidental contact with them. Ample room is provided in back of the switchboard so as to mount contactors with plenty of head-room underneath. All control wiring is run in conduit laid in the cement floor and terminates in a pit at the switchboard. All wiring is brought to a terminal board on the bottom of the switchboard and from there to various instruments and relays. Resistances are mounted on the top section of the panels so as to provide ample access to the switchboard wiring.

On account of the rapid growth of the power system it was not possible to delay the erection of stations till the automatic equipment was delivered so that practically all of the installations were made in a temporary manner as hand stations and were operated as such through summer periods and the installation of automatic equipment was done during this period. The first stations installed were those at Beach and Kenosha, followed by those at Four Mile, Lake Bluff, Libertyville and Ravinia, the last is just being put in service. All of these stations are 25-cycle equipments except Ravinia, which is 60-cycle. All the 25-cycle stations are laid out for 33,000-volt service, but some are temporarily operating 13,200 volts. The 60-cycle station is operating at 20,000 volts with provisions for 33,000-volt operation at some future data.

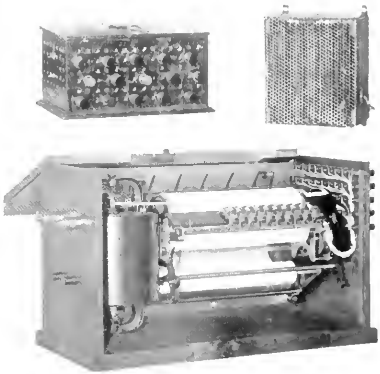


Fig. 11. Instrument That May be Employed to Automatically Record the Operation of the Various Devices of an Automatic Substation Equipment

From the start it was apparent that it was very desirable to know what occurred in the automatic substations, between inspection periods; accordingly, a number of mechanical counters were attached to various pieces of the apparatus in such a manner as to record the number of operations. This gave a very close check on how the station was acting and up to a very short time ago no other checking method was available. However, the manufacturer has since developed a recording instrument, Fig. 11, which gives a very complete record of station operation by means of an ammeter element and nineteen recording pens actuated by various pieces of the equipment.

The inspector reads these various counters on daily inspection and enters them on a report card which is sent to the office and tabulated on a monthly sheet, as shown in Table II. In this way the various operations of the station can be followed from time to time. It is from this record that the operating statistics are obtained. In addition to this record, a log book is kept in each station in which these same readings are entered daily, together with a report on all failures or unusual occurrences. A Bristol recording voltmeter chart is used for indicating when the station is on and off the line, and from this the time of operation is calculated every day.

From Table III it is quite apparent that the stations have been given a very severe tryout and if any serious defects existed they would have shown up by this time. At the Kenosha station, which has made over 33,000 operations since its installation, there has been no appreciable wear or excessive maintenance on any of the apparatus. In fact, the main contacts on which most of the wear occurs have never been removed and from our experience to date it is impossible to determine what the life will be or what the maintenance will amount to. As far as the number of operations are concerned, Kenosha station has had the equivalent of 22.7 years of service as a hand-operated station, assuming four operations per day in a hand station. This means a correspondingly heavy service on the balance of the equipment and the result speaks very well for the substantialness and ruggedness of the design. The average operating load on the Beach and Kenosha stations is considerably higher than is possible to obtain in hand-operated stations and is due to the load-limiting resistance keeping down the momentary peaks, thereby making it possible to carry a considerably heavier load on automatic than on hand-operated stations. While this is a feature which can be applied to manual as well as automatic stations it is nevertheless a regular feature of automatic equipment and this type of station should be given credit for it.

Among operators of this type of equipment, there has been considerable controversy as to the frequency of inspection required and on various properties this has been from daily to weekly. The amount required undoubtedly depends upon the load on the equipment, the reliability expected, and the seriousness of an occasional failure. From an inspection of our operating records we believe that with as complicated a piece of apparatus as this, which performs as large a number of operations, and where absolute reliability is required, a reasonable close inspection is needed, so that we are of the opinion that daily inspection is about what is needed, when coupled with recorders which give an indication of what goes on between inspection periods. A typical section of a recording ammeter chart is shown in Fig. 12, which indicates the character of the load on a 500-kw. station.

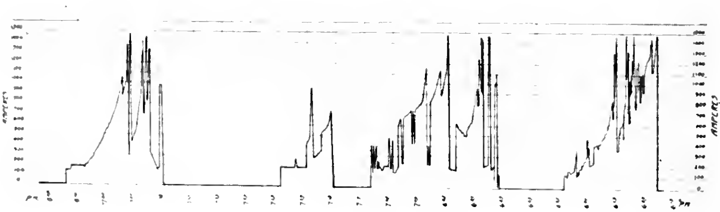


Fig. 12. Typical Section of Recording Ammeter Chart, Kenosha Automatic Substation

As the automatic substation design is only in its infancy, it was to be expected that some failure would result and that the design of certain pieces of apparatus would have to be changed. This was the case, but from Table IV it is quite evident that the failures have been comparatively few in number and are of a minor nature. Since the causes have been located, a great many of the failures have been eliminated entirely. A summary of this

TABLE I

GENERAL STATISTICS

Year	Car Miles Operated: Passenger	Car Miles Operated: Freight	Passengers Carried	A-c. Kw-hr. Used on Interurban System	A-c. Kw-hr. per Car mile on Interurban System
1915	2,450,988	272,088	6,762,518	15,160,975	5.78
1916	2,830,317	348,320	7,459,689	17,892,122	5.83
1917	4,034,352	443,762	10,374,243	23,207,845	5.45
1918	5,355,632	517,744	11,875,249	28,481,021	5.05
1919	6,128,254	457,264	12,425,631	28,309,649	4.67
1920	7,074,419	887,399	13,388,238	29,314,722	4.31

TABLE II

BEACH AUTOMATIC SUBSTATION, JANUARY, 1921

Number of Operations of Apparatus Between Inspections

Day	Date	Time Since Last Inspection	Hours Station Run Since Last Inspection	A-c. Kw-hr.	D-c. Kw-hr.	Controller	Oil Switch	Contactors: 18	Contactors: 20	Contactors: 19	Contactors: 21	Relay 27 A	Grid Thermostat	Average per Hr.: D-c. Kw-hr.	Average per Hr.: Operations of Station
Sat.	1	25-00	18-30	6625	5570	21	21	21	50	0	17	0	0	310.1	0.81
	2	24-00	18-45	6670	5610	14	14	11	83	0	32	0	0	299.2	0.583
	3	23-00	17-30	6835	5750	21	21	21	82	2	64	2	0	328.2	0.915
	4	24-00	17-15	6045	5070	21	21	21	65	0	33	0	0	294.	0.875
	5	24-00	17-00	5575	4670	18	18	18	53	0	39	0	0	274.1	0.75
	6	24-00	16-45	5470	4570	16	16	16	14	0	14	0	0	273.	0.667
	7	24-00	17-15	5510	4610	16	16	16	49	0	15	0	0	267.5	0.667
	8	24-00	18-15	5785	4830	17	17	17	36	0	41	1	1	264.7	0.708
Sun.	9	25-00	18-00	6280	5260	21	21	21	51	1	25	0	0	292.2	0.84
	10	22-00	16-15	5750	4830	18	18	18	37	0	11	0	0	297.2	0.818
	11	25-00	16-30	5875	4920	22	22	22	69	0	7	0	0	298.1	0.88
	12	24-00	16-30	5525	4620	22	22	22	41	0	41	0	0	280.	0.917
	13	24-00	19-00	6540	5460	18	18	13*	78	1	72	1	1	285.8	0.75
	14	24-00	18-00	5840	4890	15	22†	20	62	5	30	0	0	271.9	0.625
	15	24-00	17-00	5875	4930	18	22†	18	50	0	59	2	1	290.	0.75
Sun.	16	25-00	20-15	7415	6240	10	23†	10	54	0	20	0	0	308.1	0.40
	17	22-00	18-30	7140	6010	3	6†	3	56	0	13	0	0	325.1	0.136
	18	25-00	18-30	6530	5470	13	25†	13	57	13	46	2	0	295.9	0.52
	19	24-00	19-20	6280	5270	9	24†	9	49	0	15	0	0	272.2	0.375
	20	26-30	21-00	7415	6250	12	20†	12	53	0	77	3	0	297.8	0.453
	21	24-00	16-45	5680	4790	24	31†	24	13	5	12	1	1	286.1	1.
	22	21-30	14-10	4355	3660	19	19	19	43	0	56	2	1	258.2	0.883
Sun.	23	24-00	15-00	5545	4620	27	27	27	62	0	11	7	0	308.	1.125
	24	23-00	17-00	6835	5830	7	7	7	39	0	98	0	0	343.1	0.304
	25	29-25	21-00	7440	6240	17	17	17	52	0	37		0	297.	0.577
	26	18-35	13-10	4080	3400	14	14	14	33	0	7	0	0	258.5	0.753
	27	25-00	18-45	6360	5360	14	14	14	50	0	34	0	0	286.4	0.56
	28	24-00	17-45	5460	4580	16	16	16	30	0	12	0	0	258.	0.667
	29	24-00	17-15	5180	4320	19	19	19	42	0	13	0	0	250.4	0.792
Sun.	30	25-00	17-30	5830	4900	22	22	22	32	0	0	0	0	280.	0.88
	31	22-00	16-30	5375	4510	20	20	20	24	0	12	0	0	273.4	0.909
Total		743-00	544-55	1871710	157040	524	593	524	1568	27	993	22	5	8915.2	21.919
Average per Day		23-58	17-35	6037.7	5065.8	16.9	19.1	16.9	50.6	.87	32.03	.71	.16	287.5	.707

*No. 18 contactor counters out of order.
†Oil switch counters out of order.

TABLE III

AUTOMATIC SUBSTATION OPERATING STATISTICS

Station	Size Unit Kw.	Date Started	Total D-c. Output to Jan., 1921	Total Hrs. Operated	Total Number of Operations	Total Operations of 1st Res. Contactor	Average Output per Operating Hour in Kilowatts	Average No. of Station Operations per Day	Average No. of Operations of 1st Res. Contactor per Day
Four Mile....	500	Nov. 2, '18	1,948,600	9712.8	24,709	9,298	200.6	31.25	11.62
Kenosha	500	April 15, '18	3,310 420	11005.0	33,141	29,159	301.0	33.4	29.4
Beach..	500	Dec. 5, '17	4,926,745	16854.0	21,562	56,387	292.0	19.4	50.2
Lake Bluff..	1000	Feb. 26, '19	3,782,630	11726.8	7,196	8,520	323.0	10.65	12.6
Libertyville	300	Dec. 6, '19	471,400	6737.0	13,980	33,323	70.0	35.7	85.1

TABLE IV
RECORD OF FAILURES

Libertyville	Lake Bluff	[illegible]	Kenosha	Beach	Apparatus No.	Name of Apparatus	Cause of Failure
	1		7		3	Time Delay Cutout Relay	Contacts burnt
	1	1	1		3	Time Delay Cutout Relay	Coil burnt out
			2	1	3	Time Delay Cutout Relay	Toggle failed to lock
	2				3	Time Delay Cutout Relay	Out of adjustment
	1				2	Instantaneous Control Relay	Open circuit
1					2	Instantaneous Control Relay	Resistance grounded
1					2	Instantaneous Control Relay	Chattering
	2	1			2	Instantaneous Control Relay	Plunger stuck
				1	1	Contact Making Voltmeter	Stuck
		1	1		34	Controller Motor	Burnt out
	1	1	1		34A	Controller Motor	Commutator dirty
	1	1	1		34	Controller Motor	Poor contact segment
			3		34B	Exciter	Polarity reversed
1					34	Controller	Brake stuck
	3	2	1	1	33	Resistance Thermostat	Contact out of pivot
	1				33	Resistance Thermostat	Contact burnt off
		1	2		7	Oil Switch	Motor burnt out
			3	2	7	Oil Switch	Guide block broke
	4				7-B	Interlock on Hand Reset	Loose contact
			6		7-B	Hand Reset Open	Defective latch
	1		3	1	30	Field Relay	Screw loose on contacts
2	1	1			30	Field Relay	Low voltage would not close
		1			30	Field Relay	Grounded
1		1	2		36	Polarized Relay	Poor contact
1			3		37	Underload Relay	Contacts burnt
					37	Underload Relay	Stuck open
		1	1	1	27	A-c. No-voltage Relay	Poor contact
		1			29	Reverse-current Relay	Burnt out, lightning
	24				35	Brush Lifting Device	Coasting not enough or too far
	2				4	Master Relay	Poor contact
	1				32	A-c. Low-voltage Relay	Resistance burnt out
					32	A-c. Low-voltage Relay	Broken lead
2					25	Load-Limiting Relay	Stuck
1					25	Load-limiting Relay	Bad contacts
1					6	Controller Motor Contactor	Grounded
				1	14	Field Contactor	Burnt contact
11	46	13	37	9		Total	

TABLE V
SUMMARY OF 48-HOUR RUNS

	Kenosha	Lake Bluff	Libertyville
Capacity of converter	500 kw.	1000 kw.	300 kw.
Total running time	1271 min.	2310 min.	2219 min.
Running time, per cent of total run	44.2 per cent	80.3 per cent	77.0 per cent
Number of starts	69	4	26
Average length of running period	18.5 min.	9.6 hrs.	1.4 hrs.
Total input to station	7536.7 kw-hr.	16080 kw.-hr.	4108.5 kw-hr.
Total output from station	6130 kw-hr.	14218 kw-hr.	3200 kw-hr.
Efficiency of station	81.5 per cent	88.5 per cent	78 per cent
Average load, per cent of mach. rating	59.7 per cent	37.3 per cent	29 per cent
Time 1st resistor was in circuit	132 min.	19.3 min.	
Time 2nd resistor was in circuit	23 min.	.94 min.	
Per cent converter output lost in resistors	2.2 per cent	.48 per cent	.2 per cent

Percentage Distribution of Input to Station

	Kenosha	Lake Bluff	Libertyville
Total output to trolley	81.5	88.5	0.78
Total consumed by resistors	1.86	0.43	0.16
Total consumed by a-c. control operating	0.16	0.11	0.27
Total consumed by a-c. control shutdown	0.041	0.006	0.027
Total consumed by a-c. control starting	0.016	0.0006	0.011
Total consumed by a-c. control stopping	0.003	0.00009	0.002
I^2R and core losses of control transformer	0.11	0.07	0.30
Total consumed by No. 32 relay	0.01	0.02	0.05
Total consumed by d-c. control	0.38	0.36	0.85
Total consumed by converter in starting and going on the line	1.01	0.02	0.34
Total losses in converter and power transformer	14.88	10.48	19.99

record is presented in Table VI and shows that the failures per 1000 operations of the various stations have been remarkably few. The high average per 1000 operations at Lake Bluff is due to defects which developed in the brush lifting device, which has since been corrected and failures from this cause eliminated.

TABLE VI

SUMMARY OF FAILURES

Station	Total Number of Operations	Total Number of Failures	Failures Per 1000 Operations
Four Mile	24,709	13	0.526
Kenosha	23,141	37	1.113
Beach	21,582	10	0.4638
Lake Bluff	7,196	46	6.392
Libertyville	13,989	13	0.929

From Table VII it is apparent that of the 119 failures the causes for 71 have been eliminated by redesigning pieces of apparatus. The remaining causes for failure are of the usual class found in all complicated apparatus and these failures can be kept at a minimum only by careful inspection and maintenance.

The final test of whether the automatic substation is to remain depends upon its ability to make a reduction in operating expenses. On the North Shore Line this has amounted to approximately $11,351 after charging against the station all legitimate charges, such as inspection, interest and depreciation on equipment, and taking credit for the elimination of station operating labor and idle running losses. This saving has been made on 10.87 station years of service, or

TABLE VII

ANALYSIS OF FAILURES

App. No.	Name of Apparatus	No. of Failures	Cause of Failure	Permanent Elimination of Failure Made by
3	Time delay cutout relay	8	Contacts burnt	Redesigned relay head and substituted new contact metal
3	Time delay cutout relay	3	Coil burnt out	
3	Time delay cutout relay	3	Toggle failed to lock	Redesigned relay head
3	Time delay cutout relay	2	Out of adjustment	
2	Instantaneous control relay	1	Open circuit	
	Instantaneous control relay	1	Resistance grounded	
	Instantaneous control relay	1	Chattering	New type of relay substituted
	Instantaneous control relay	3	Plunger stuck	New type of relay substituted
1	Contact making voltmeter	1	Plunger stuck	
34	Controller	3	Motor commutator dirty	Daily cleaning eliminates trouble
		2	Motor burnt out	
	Controller	3	Poor contact on contact segment	
	Controller	3	Exciter reversed	
	Controller	1	Brake stuck	
33	Resistance thermostat	7	Contact jumps out of pivot	Thermostat design changed
		1	Contact burnt off	
7	Oil switch	3	Motor burnt off	Operating mechanism redesigned
		5	Guide block in switch broke	Design of block and fastening changed
7B	Trip switch latch	6	Defective latch	Readjusted
	Trip switch interlock	4	Loose contact	
30	Field relay	5	Contact screw loose	
	Field relay	4	Would not close in low voltage	Coil winding changed
	Field relay	1	Winding grounded	
36	Polarized relay	3	Poor contact	Contacts changed
37	Underload relay	4	Contacts burnt	Contacts changed
	Underload relay	4	Stuck open	
27	A-c. No-voltage relay	3	Loose contact	Relay redesigned
29	Reverse-current relay	1	Burnt out by lightning	
35	Brush lifting device	24	Coasting too much or not	Mechanism redesigned
4	Master relay	2	Poor contact	
32	A-c. low-voltage relay	1	Resistance burnt out	
	A-c. low-voltage relay	1	Broken lead	
25	Load limiting relay	1	Stuck	
	Load limiting relay	2	Bad contacts	
6	Controller motor contactor	1	Coil grounded	
14	Field contactor	1	Contacts burnt	
	Total	119		

$3,804 per station year, or expressed on a basis of kilowatt-hours converted amounts to a reduction of 0.2863 cent per direct-current kilowatt-hour.

We have just completed a very comprehensive series of tests on three of these stations, in conjunction with the General Electric Company, for the purpose of determining exactly the losses which occur in the stations due to automatic operation. During these tests a great many interesting facts were found which have done considerable toward increasing our confidence in the equipment and the savings which are possible due to their operation.

Table V is a summary of a 48-hour efficiency run made on each of the stations under test and shows the efficiency of the stations and the distribution of losses in the various parts of the equipment.

The automatic substation has been one of the greatest developments which has taken place in the railway power field in recent years and its advent has to a large extent made radical changes in power distribution engineering, which is going to result in higher efficiency and better operating conditions on properties where it may be employed. Its field of application is practically unlimited, but the details of application and modification which may be required to suit certain localties are problems which must be studied and worked out for each location. On first consideration the automatic substation appears to be a very complicated piece of apparatus, but when we consider that it performs practically the same functions as the multiple-unit car control has done for years under a great deal more severe conditions than exist in a substation, there is no reason why it should not be very satisfactory. Our own experience has borne out these facts and we are very well satisfied with the results obtained.

A Brief Review of Automatic Substation Experience on the Aurora, Elgin & Chicago R. R.

By S. E. Johnson

Engineer Overhead Construction, Aurora, Elgin & Chicago Railroad

The experiences of the Aurora, Elgin & Chicago R. R. with a single automatic substation are descriptive of a quite different service from that required of the North Shore Lines. Inspection periods are seven days apart and the control equipment is adjusted to furnish the maximum possible amount of power throughout the 24 hours. The object of this method of operation is to obtain improved voltage conditions which assist in maintaining heavy schedules with three to six car trains. A unique signalling system operating over the dispatcher's telephone line warns the dispatcher of any failure of the substation. This article was originally presented as a discussion of Mr. C. H. Jones' paper found elsewhere in this issue.—Editor.

The article on "Results of Automatic Substation Operation on the Chicago, North Shore & Milwaukee R. R.," which appears elsewhere in this issue, treats of a system where there is enough inspection work connected with the substations to warrant a crew of men for this work alone. Consequently, the electrical engineer of the road has been able through his organization to compile data not only very valuable in the efficient operation of his own system but which can be used as a basis of calculation for other systems of like character. The follow-up system on causes of failures is especially interesting and valuable to other companies.

The system described is a large one and I believe that the crew now employed exclusively on automatic substation work could successfully take care of twice the number of stations that they now have. On a smaller system where there are but one or two installations, the inspection work must be handled by the regular substation operators or repair men and their work must be checked more closely by their foreman or the chief operator of substations on account of the automatic substation inspection being a sort of side line with them. On the other hand, men engaged in automatic substation work exclusively become very proficient and can more efficiently make the necessary inspection and adjustments.

On the Aurora, Elgin & Chicago Railroad we have seven manually controlled substations and one automatically controlled. This station was originally manually controlled, but was changed over to automatic in September, 1918. It is located approximately ten miles from the nearest hand-operated substation. An hourly schedule is operated both ways with trains consisting of one to three cars through the winter. During the summer months very heavy picnic service is operated on this branch, and these trains usually have about six cars.

Some Unusually Severe Operating Conditions

The service under which this station must operate during the summer months is very severe; probably more severe than automatic substations were originally intended to serve. The starting current drawn by our particular car equipment is heavy, and on account of the exceptionally long distance between substations, the automatic equipment must naturally take care of practically all of the current taken by trains until they are well away from the station. This made it necessary to set the thermostat on the line resistance grids so high that the grids would be at red heat before the machine would be cut off. It took considerable thought and experimenting before we arrived at a proper setting of the thermostats controlling the grid resistance. The exceptionally heavy picnic service requires, for a definite period, considerably more than the capacity of the rotary converter. We had no data available as to the temperature at which the thermostats should be set and as it was absolutely necessary to furnish a maximum amount of power from this particular rotary for a definite period, the proper setting of the thermostats resolved itself into a matter of time rather than temperature rise; and the setting necessary was accomplished by a personal observation of the performance of the grids and a gradual raising of the setting of the thermostat to a point where it was required that the grids be at a dull red heat before the thermostat functions. By this means any cars in the vicinity of this substation are given power to move them, regardless of this excessive heating, until they are well away from the station and are taking current from another station. Where a complete installation of automatic equipment is made on a system and the stations are spaced according to present day practice, that is, from four to five miles apart, the load-limiting resistance would not be called upon to carry this extremely heavy overload; but where the stations are located as they are on this system, the heavy setting is necessary in order to obtain the maximum output of the station.

When the station was placed in operation, the matter of regular inspection was given a great deal of study. A careful survey of the practice of other companies in this respect was made, and from the information gathered the period of inspection was found to range from daily to weekly, most companies, however, inspecting daily. We finally adopted the weekly inspection, partly because we had no organization to handle a more frequent inspection, but more especially because we felt that an automatic substation to be entirely successful should run for a longer period than twenty-four hours without any attention whatever. We did, however, for the first two or three months carefully follow the operation of the station by beginning with daily inspection, then extending it to an inspection every two days, and increasing the period between inspections up to twelve days, and decided from our experiments that the limit of inspection should be approximately seven days as there were parts of some relays that became loosened and out of adjustment in a ten-day period that remained in proper adjustment for a seven-day period. It was primarily this experiment that led us to adopt the weekly inspection, and we have followed it religiously since with very good results. In addition, we make an inspection after each electrical storm, though no difficulties have ever shown up. An operator who lives in the vicinity charges the lightning arresters, takes the meter readings and changes the recording voltmeter charts daily, but does no further inspection work. This can be entirely eliminated by the use of weekly charts and oxide film lightning arresters.

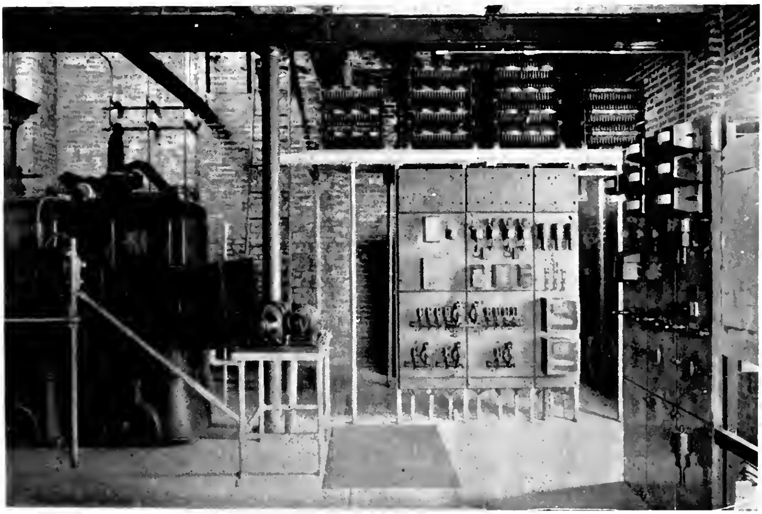
This procedure soon brought us to the conclusion that we must know what was happening between inspection periods, that is, we must know if the station failed and also the number of failures; and we soon developed and installed a special signal device that notifies the train dispatcher in case the station does not come in on the line properly when a demand requires it. This signal device was developed by the writer and consists of a long time element relay (ten minutes) that operates directly from the No. 2 relay as follows: Each time there is a demand made upon the station this signal device operates a common ringing and listening key similar to those installed on automatic telephone switchboards, giving a ring on the line with the 25-cycle current, calling the dispatcher to the telephone line, and upon completing the ringing connects to the line an ordinary telephone on the transmitter of which has been attached a specially pitched buzzer. It is arranged that this signal is given three times during the ten-minute interval. This signalling is not started until two minutes have elapsed from the time of the demand made on the station and if the rotary comes in on the line properly a relay operated from the auxiliary switch on contactor No. 18 picks up and prevents the signal from going out on the dispatcher's telephone line. This device has allowed us to forget about the automatic station between inspection periods. A record of the number of complete operations of the station is made by the use of a Bristol recording instrument. We have averaged one failure per 750 operations.

By the installation of automatic equipment at our one station we were able to save $11.90 per day in labor alone, and we feel certain that we also save a considerable amount in repairs, but this we are unable to check. The average daily output has increased from 4,000 kw-hr. per day to 6,500. This is due to the fact that under manual control a train starting at the station knocked out the circuit breaker on the rotary and it was then impossible to close it again until the train was some distance away. Under automatic operation, however, the load-limiting feature permits the station to furnish power to the train continuously. Another advantage is that the service on this branch is improved, as we are able successfully to handle heavier trains under better voltage conditions.

The stations mentioned in Mr. Jones' article, previously referred to, operate a good many times a day, one in particular sixty-nine times. I believe that a station can operate too many times per day. In this particular instance, the station perhaps operated five or six times per hour during rush periods, and if this is true, I believe it would be advisable to install a device that would hold the machine in on the line during this period and thus save the wear and tear that result from these additional stops and starts.

On our system we have a period between 1:30 a. m. and 5:30 a. m. when there is no train service, but have deemed it advisable to hold the station on the line with a time clock to improve voltage conditions at our shop located about five miles away.

Automatic substations are now an accomplishment and no longer an experiment. They are truly reliable, more so in fact than manually controlled stations, and they will show great economy right from the start.



Interior of the Warrenville Automatic Substation of the A. E. & C. R. R., Showing Automatic Control Equipment

Efficiency and Operating Tests on the North Shore Automatic Substations

By Cassius M. Davis

Railway and Traction Engineering Department, General Electric Company

No such critical analysis of the automatic substation has before been made public as is here given by Mr. Davis in the review of the exhaustive tests conducted on three typical substations of the C. N. S. & M. R. R. Machines of three different capacities were tested including both commutating and non-commutating pole types. Stations were selected which give three different types of duty; first, practically continuous service with occasional sustained overloads; second, frequent shutdowns with long periods of no-load demand and heavy loads when running; and third, an intermediate condition. Operation is the real test of any scheme or device, and these data are a sweeping endorsement of the automatic substation for railway service.—Editor.

In the latter part of Mr. C. H. Jones' article, published elsewhere in this issue, mention is made of certain tests which had been made on some of his automatic substations. As only the general results are included, this article has been prepared to describe how the tests were made and to give in detail the results that were obtained.

Three substations were tested, Lake Bluff, Kenosha, and Libertyville. The relative locations of these substations will be found on the map shown in Fig. 1 of Mr. Jones' article. These particular ones were chosen for the following reasons:

(1) To include three different capacities of converting apparatus.

(2) To include both commutating and non-commutating pole converters.

(3) To include machines of both old and new designs.

(4) To obtain operating characteristics on substations subjected to widely varying types of load.

The chief features concerning each substation are set forth in Table I.

Up to the time these tests were made in January, no automatic substation in commerical operation had been subjected to a critical determination of its efficiency and the power losses in the control circuits and load limiting resistors; nor had accurate measurements been made of the energy required to place a substation in operation when starting from rest. The primary object in making the tests was, therefore, to measure as accurately as possible all the losses and to account for every kilowatt-hour entering the substation from the high-tension line.

Through the hearty cooperation of Mr. Jones' organization and the resources of the General Electric Company, it was possible to assemble a large amount of special apparatus, recording meters, graphic instruments, etc., and to provide ample personnel to make a very comprehensive set of tests.

TABLE I

Substation	Lake Bluff	Kenosha	Libertyville
Kw. capacity	1000	500	300
Frequency	25	25	25
High-tension voltage	13,200	33,000	13,200
Converter transformer, kv-a.	3-350	3-185	3-110
Converter rating	4-pole, 6-ph.	6-pole, 6-ph.	6-pole, 3-ph.
Commutating poles	Yes	No	No
Date of converter design	1917	1905	1901
Weight of complete converter	20,800 lb.	32,800 lb.	22,500 lb.
Weight of armature and shaft	7000 lb.	7300 lb.	5800 lb.
Diameter of armature	31.5 in.	36.0 in.	36.0 in.

Note.—Each substation is equipped with standard General Electric automatic railway control. The transformers at Lake Bluff are of the inherent reactance type. At Kenosha and Libertyville, external compounding reactors are used.

The general routine followed in making the tests on each substation consisted of:

(1) Measurement of the voltage and current, and the watts consumed by each individual device.

(2) The voltage and current, and the watts consumed by various groups of devices as connected in the several sequences of operation.

(3) Running-light high-tension input of the converter and transformers.
(4) High-tension input required to start the equipment from rest and to put it on the line.
(5) Forty-eight-hour continuous run in regular service.
(6) Oscillograph records of performance of equipment under various conditions.

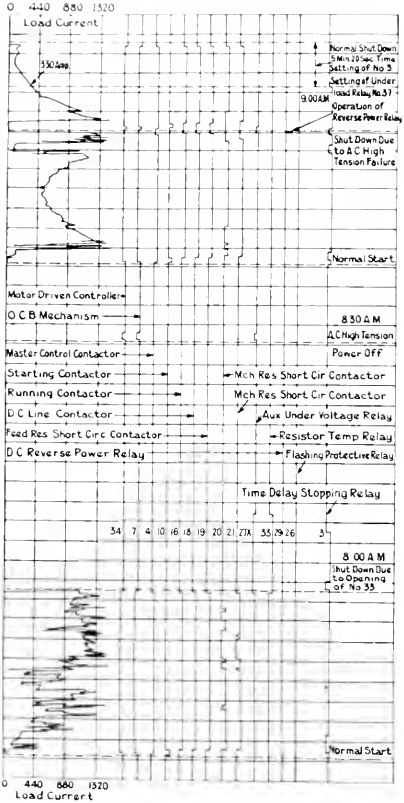


Fig. 1. Section of Automatic Station Recorder Chart Made During Run on Kenosha Substation

All readings were checked as closely as possible with known design data, and wherever possible indicating wattmeter readings were compared with those yielded by rotating standards. During the 48-hour runs a continuous record was made of the a-c. power, energy, and current input; a-c. control input; d-c. energy, voltage, and current output; and the energy loss in load limiting resistors.

In addition to these energy and power records a continuous graphic record was obtained of the operations of the more

TABLE II

Device No.	A-c or D-c	Energized From: Control Transf.	Power Transf.	Converter Armature	Trolley Circuit
1	d-c.				*
2	a-c.	*			
3	"	*			
4	"	*			
5	"	*			
6	"	*			
7	"	*			
10	"	*			
14	"	*			
16	"	*			
17	d-c.			*	
18	"			*	
19	"			*	
20	"			*	
21	"			*	
27	a-c.	*			
27A	"	*			
29	d-c.			*	
31	a-c.	*			
32	"		*		
34	"	*			
36	d-c.			*	
37	"			*	

Note.—Series devices such as No. 23, 26, 28, etc., are not included.

TABLE III

Device No.	Energized When: Shut Down	Starting	Running	Shutting Down
1	*	*	*	*
2		*	*	
3		*	*	
4		*	*	
5		*	*	
6		*		*
7		*	*	
10		*		
14			*	
16			*	
17			*	
18			*	
19			*	
20			*	
21			*	
27	*	*	*	*
27A	*	*	*	*
29			*	
31		*		
32		*	*	
34		*		*
36			*	
37			*	

Note.—Series devices such as No. 23, 26, 28, etc., are not included. Device No. 1 is energized from the trolley when the station is shut down.

important devices. These last records and the direct-current output were secured by means of the specially constructed recorder shown in Fig. 11 of Mr. Jones' article. A portion of the record made by this instrument is exhibited in Fig. 1.

The energy loss in the load limiting resistors was measured by a specially calibrated watt-hour meter, the current coil of which was connected in series with the resistor circuit while the potential coil was connected across the resistor circuit. The values obtained were checked by determining the average current and time from the graphic recorder chart and calculating the loss.

In order to appreciate the manner in which the incoming substation energy is distributed in an automatic substation, the general scheme of operation must be borne in mind. The bulk of the control apparatus is operated by power received from a control transformer. This transformer is connected to the transmission line outside the station oil circuit breaker, and hence it is always energized. A few devices are operated by d-c. power taken from the converter when the latter is running. One relay (No. 32) is energized from the secondary of the power transformers. One relay (No. 1) receives power from the trolley circuit and this power is not charged against the substation while not in operation.

By reference to the wiring diagram, Fig. 2, it will be observed which devices receive power from the different sources mentioned. For convenience they are given in Table II.

The sequence of operations when starting up the substation is briefly as follows: When relay No. 1 operates, due to low voltage on the trolley circuit, the controller No. 31

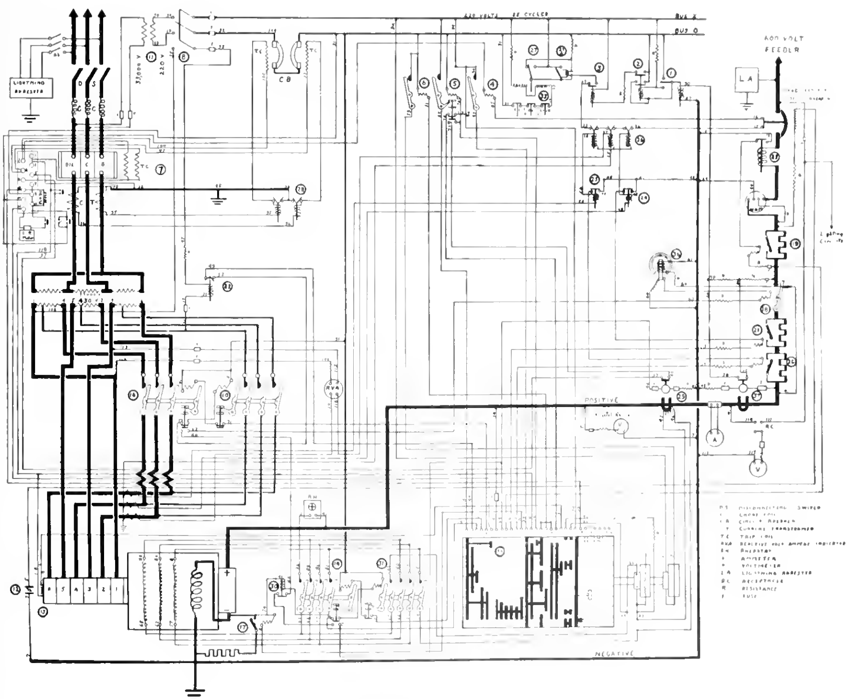


Fig. 2. Wiring Diagram of Kenosha Substation

starts. The controller segments then make contact in sequence closing the oil circuit breaker, No. 7, and then the starting contactor, No. 10. The converter then starts and runs up to synchronous speed. The converter is then polarized by the operation of contactors Nos. 31 and 14 in succession. Then the running contactor, No. 16, closes and in succession contactors Nos. 17, 18, 19, 21 and 20; the last three short circuit the steps of the load limiting resistors. The controller then stops and remains in this position as long as the converter is required for load. When the load demand disappears and relay No. 3 opens, all contactors carrying the load current on both the a-c. and d-c. end of the converter open and the controller is re-started to move it to the "off" position.

Some devices are energized when the converter is shut down, some while it is starting up and shutting down, and some while it is running. Table III shows which ones belong to each group.

While the above description applies strictly to the Kenosha Substation, it will also answer for the other two substations although there are slight differences in the equipment.

The substation incoming energy may be segregated as follows:

A Input to alternating-current control circuit.

(1) Station shut down.
(2) Station starting up.
(3) Station running.
(4) Station shutting down.

B Input to power transformers.

(1) Station starting up.
(2) Running light losses in transformers and converter.
(3) Relay No. 32.
(4) Direct-current output of converter.
 (a) Direct-current control, station running.
 (b) Losses in load limiting resistors.
 (c) Direct-current output to trolley circuit.

C Copper losses, load losses, etc., in transformers, converter, instruments, etc.

Definite measurements can be made and values assigned, once for all, to each of these items, except that under the heading of "Copper losses, load losses, etc." The values for this item depend upon the character of the load. In the tests herein discussed this item represents the difference between the total incoming power and the sum of the values of all the other items.

TABLE IV

Substation	Lake Bluff	Kenosha	Libertyville
Kw. capacity	1000	500	300
A Input to a-c. control circuit:			
(1) Station shut down, watts	343.0	230.0	360.0
(2) Station starting up, watt-hr	25.4	18.0	19.4
(3) Station running, watts	699.0	687.0	333.0
(4) Station shutting down, watt-hr.	3.7	3.0	2.8
B Input to power transformers:			
(1) Station starting up, watt-hr	893.0	1170.0	535
(2) Running light losses, kw	28.8	36.0	18.0
(3) Relay No. 32, watts	65.0	52.0	42.0
(4) D-c. control, station running, watts	1502.0	1372.0	935

The results of the tests made on the three North Shore substations are shown in Tables IV and V. The former gives values for all those items which do not depend upon the direct-current output of the substations; the latter gives the results of the 48-hour runs in regular service.

Some explanations of Table IV are necessary. The variations in the power required by the alternating-current control are due primarily to the size of contactors in the different substations. Relay No. 2 in Libertyville is a smaller device than in the other two substations. In Kenosha, contactors Nos. 4, 5, and 14 are of 150-ampere capacity while in the other two substations the corresponding devices are of 75-ampere capacity. The running contactor, No. 16, in Lake Bluff is larger than those in Kenosha and Libertyville and takes a little more power. The control transformers in Lake Bluff and Libertyville are larger than those at Kenosha, and consequently the core loss is higher in these two. The net result is as indicated in the table.

The values of energy required to start up the substations and the running light losses are interesting because they show the effects of different converter designs. The machines in Kenosha and Libertyville are of old design, having heavy armatures of large diameter and low speed. The one in Lake Bluff is of modern high-speed design, and although twice the capacity of the Kenosha converter, its armature is only 7/8 the diameter and 96 per cent as heavy. The Lake Bluff converter reaches synchronism from rest in five seconds, while it requires 14 seconds for each of the other machines. The starting energy is very nearly in proportion to the running light power and in each case represents the same energy as is required to run the converter light for about two minutes.

The difference in direct-current control power is due to the number of resistor contactors in the respective substations.

The summary of the 48-hour run given in Table V is very interesting and shows just where all the incoming substation energy was consumed. This tabulation is similar to that given in Mr. Jones' article but it has been re-arranged slightly to correspond to the classification previously mentioned. The energy consumption by the alternating-current control has been re-calculated to include the core loss of the control transformer, while the I^2R loss in this transformer has been lumped in with the total substation copper loss, etc., under item "C."

The effect of the train service on the substation operation is noticeable. Lake Bluff supplies a diversity of load consisting of limited and local trains from Chicago to Milwaukee, and express trains from Chicago to Waukegan. It also supplies one end of the branch west through Libertyville to Area. As a result there is practically always a load demand on this substation. Three of the starts and stops recorded during the run occurred between the hours of 1 a.m. and 7 a.m. The other one was due to a heavy sustained overload which operated the resistor thermostat. The maximum output to the

TABLE V

Substation	Lake Bluff	Kenosha	Libertyville
Capacity, kw	1000	500	300
Total time running, min.	2310.0	1271.0	2219.0
Total time running as percentage of 48 hrs., per cent	80.3	44.2	77.0
Number of starts	4.0	69.0	26.0
Number of stops	4.0	68.0	27.0
Average length of running periods	9.6 hr.	18.5 min.	1.4 hr.
Total input to substation, kw-hr.	16,080.0	7536.7	4108.5
Total ouput of converter, kw-hr.	14,344.7	6298.8	3241.1
Total ouput to trolley circuit, kw-hr	14,218.0	6130.0	3200.0
Over-all efficiency of substation, per cent	88.4	81.3	77.9
Average load on converter during running time, kw	373.0	297.0	87.8
Time load limiting resistors were in circuit, min	20.2	155.0	Not Measured

Distribution of Input	Lake Bluff Kw-hr.	Lake Bluff Per Cent	Kenosha Kw-hr.	Kenosha Per Cent	Libertyville Kw-hr.	Libertyville Per Cent
A A-c. control circuit:						
(1) Input while station was shut down	3.3	.021	6.2	.082	4.0	.097
(2) Input while station was starting up	0.1	.001	1.3	.017	0.4	.010
(3) Input while station was running	27.0	.168	14.5	.192	19.5	.475
(4) Input while station was shutting down	Negligible		0.2	.003	0.1	.002
B A-c. power circuit:						
(1) Input while station was starting up	3.5	.022	80.7	1.07	13.9	.338
(2) Running light losses	1110.0	6.91	763.	10.12	694.6*	16.88
(3) Energy consumed by relay No. 32	2.5	.016	1.1	.014	2.0	.049
(4) D-c. converter circuit:						
(a) D-c. control while station was running	57.7	.359	28.8	.382	34.6	.842
(b) Losses in load limiting resistors	69.0	.429	140.	1.86	6.5	.158
(c) Output to trolley	14,218.0	88.41	6130.	81.34	3200.0	77.92
C Copper losses, load losses, series devices, etc.	588.9	3.66	370.9	4.92	132.9	3.23
Total high tension input to substation	16,080.0	100.00	7536.7	100.00	4108.5	100.00

*This includes 29.6 kw-hr. core loss in power transformer.
The transformers in this station are not disconnected when the converter shuts down.

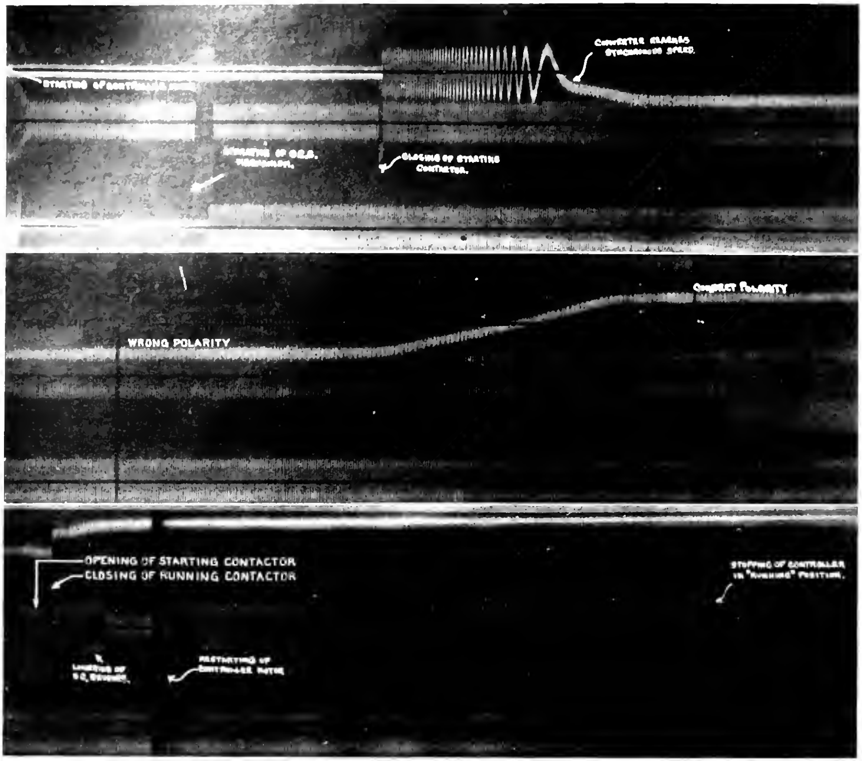
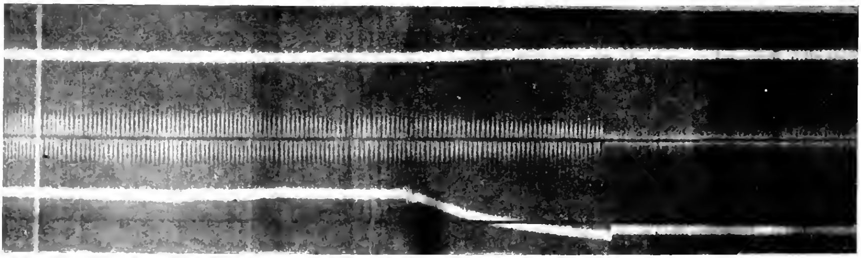


Fig. Continuous Oscillogram (in three parts), Showing Complete Starting Cycle of Lake Bluff Substation



Substation Due to Interruption of the High Tension Supply trolley circuit during any one hour was 535 kw-hr. The average output was 296 kw. This gives a load-factor of 55.3 per cent, and a station-factor of 29.6 per cent.

At Kenosha the situation is quite different. This station is near a passing point and supplies the limited and local Milwaukee service only. There are long periods each hour when there is no load demand. Consequently, this substation starts and stops frequently and carries a heavy load whenever it is operating. The maximum hour output during the 48-hour run was 310 kw-hr., while the average load was 128 kw. The load-factor was 41.3 per cent and the station-factor was 25.6 per cent.

At Libertyville an intermediate condition exists. This substation feeds a stub end where the traffic is light. Most of the starts and stops take place during the early afternoon and between midnight and 6 a.m. The lay-over at Area is ordinarily not long enough to permit of a shut-down. The maximum hour output to the trolley was 141 kw-hr., the average output 66.7 kw., the load-factor 47.3 per cent, and the station-factor 22.2 per cent.

All the foregoing values are based on the total run of 48 hours. The real story is told however by basing the load calculation on the actual time the automatic substation is in operation. Consequently, the following values have been prepared and tabulated in Table VI. These figures bring out clearly the duty to which each substation is subjected. The Kenosha record is particularly worthy of note, since it is carrying about all it is possible for a 500-kw. machine to handle in heavy interurban service. In fact, were it not for the load limiting resistor, it would be impossible for a machine of such small capacity to carry the loads imposed upon it.

The slight differences between the values of "Station-Factor" as shown in Table VI and "Average load, per cent of machine rating" as shown in Table V in Mr. Jones' article are due to the use, as a basis, of the output of the converter in the latter.

TABLE VI

Substation	Lake Bluff	Kenosha	Libertyville
Capacity, kw	1000	500	300
Total time running, hr	38.5	21.18	36.98
Total time shut down, hr	9.5	26.82	11.02
Total output to trolley, kw-hr	14,218.0	6130.0	3200.0
Average output to trolley, kw	370.0	290.0	86.5
Maximum hour output, kw-hr	535.0	310.0	141.0
Load-factor per cent	69.2	93.5	61.4
Station-factor per cent	37.0	58.0	28.8

Of the oscillograms, two of general interest are shown in Figs. 3 and 4. The first exhibits a complete starting cycle at the Lake Bluff substation. The upper record shows the potential across the commutator brushes, the middle record is the alternating-current control current, and the lower shows the high-tension potential at the terminals of the power transformers. It will be observed that the converter, which reaches synchronism very quickly, came up to speed with the wrong polarity. The field coils were then separately excited from the small generator connected to the controller motor. The machine then slipped a pole and quickly came up with the correct polarity. The point at which the separate excitation was applied is clearly indicated. The other features of the cycle are marked on the film. Had the converter come up with the correct polarity the separate excitation would have been applied just the same, but no change in the relative position of the field flux and the armature flux would have resulted.

Many oscillograms were taken showing the behavior of the equipment under various abnormal conditions. The one illustrated in Fig. 4 shows what happens when the high-tension supply is suddenly interrupted. While the machine was carrying load, the air break switch just outside the station was opened. It will be seen that the direct-current current (lower record) falls and reverses (due to power being fed from the trolley), causing the reverse current relay to operate and trip the alternating-current control circuit (middle record). Since the load that was being carried at the time was small, the trolley voltage, shown as the upper record, did not change much. The zero line for the trolley voltage is not shown; it is above the upper record.

The tests outlined herein and the systematic performance records kept by the North Shore organization tell the complete story of the most up-to-date and economical method of furnishing power to electric railways.

Electrification of the Paulista Railway, Brazil, South America

By W. D. Bearce

Railway and Traction Engineering Department, General Electric Company

To the list of high-voltage direct-current railway electrifications already in successful operation is soon to be added the Paulista Railway of Brazil. The substitution of electricity for steam as motive power on this road is being made first on the division between Jundiahy and Campinas, a double-track section 45 km. (28 miles) in length. However, the immediate plans of the Company contemplate the extension of this electrification over the adjoining division from Campinas to Cordeiro, a distance of 72 km. (45 miles), making a total of 117 km. (73 miles). All the apparatus and equipment is of such design and capacity as to be suitable for operating over the probable continuation of the electrification to Sao Carlos, an overall distance of 206 km. (128 miles).—Editor.

The motive power equipment consists of eight freight locomotives weighing 100 tons each and four passenger locomotives weighing 120 tons each. Work has been progressing on these locomotives for about a year at the Erie Works of the General Electric Company, and the first locomotive was put on the test track about the middle of March. Complete running tests were made and two freight locomotives were shipped before the middle of May. One of the passenger locomotives was also put on the test track and shipment was made during the month of May.

In addition to the locomotives, the contract included the equipment of a complete 3000-volt direct-current substation of 4500-kw. capacity, consisting of three 1500-kw., three-unit motor-generator sets, transformers, switches, and high-tension equipment. Overhead line material has also been furnished for 122 km. (76 miles) of track and material for 16 km. (10 miles) of 88000-volt 3-phase 60-cycle high-tension transmission in duplicate from the lines of the Sao Paulo Light & Power Company.

The line from Campinas to Jundiahy is a main line section connecting at the southern terminus with the Sao Paulo Railway and the Central Railway of Brazil. The Central Railway is government owned and electrification of this line has also been authorized. At Campinas and other points north, connection is made by the Paulista Railway with a number of feeder lines which bring large quantities of coffee and other raw material from the interior.

The roadbed is rock ballasted and the construction throughout is equal to that of any main line roads in the United States. The track gauge is 5 ft. 3 in. on the section to be electrified, but some of the connecting lines are narrow gauge and facilities are provided for transferring the car bodies complete with merchandise to narrow-gauge trucks and vice versa. The passenger service includes high-speed trains with full

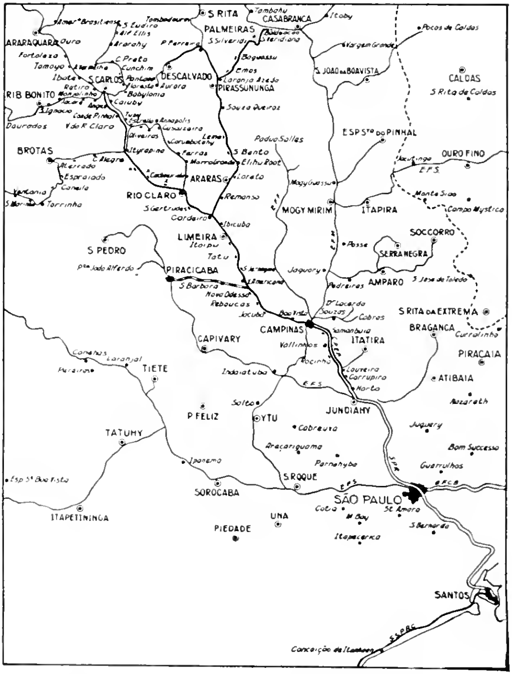


Fig. 1. Map of the Wide-gauge Section of the Paulista Railway and Connecting Lines

Pullman accommodations. The present locomotive equipment consists of heavy-type locomotives for freight service and high-speed engines for passenger service. All are equipped for burning wood as fuel instead of coal. On account of the high price of coal and the great difficulty in securing it, wood is burned almost exclusively in this part of South America. The variety most used is known as quebracho, which gives satisfactory results except that the quantity required for a 100-mile run is very bulky. Recently there has been difficulty in procuring wood that is suitable for this work. Electrification, therefore, was decided upon as the remedy.

LOCOMOTIVES

The initial equipment of locomotives includes eight freight and four passenger, all of the twin-geared type. These are similar to those in successful use in the United States on the Chicago, Milwaukee & St. Paul Railway, the Butte, Anaconda & Pacific Railway, the Detroit River Tunnel and other roads, and include the well tried features of the best types of locomotives now in service.

Freight Locomotives

The freight locomotives weigh 100 tons or approximately 91 metric tons and all the weight is on the driving axles. They are designed for handling a trailing train of 700

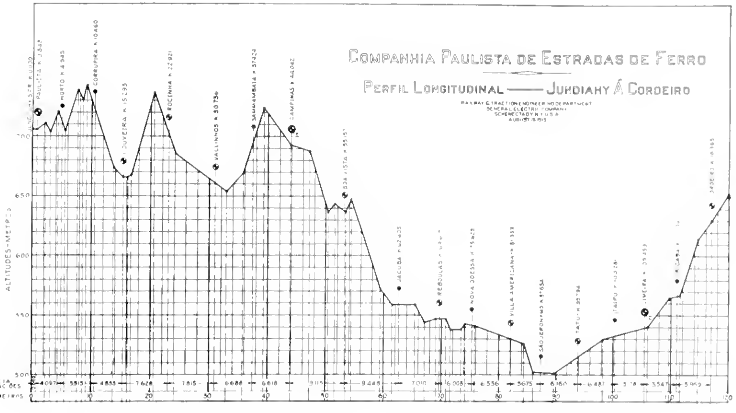


Fig. 2. Profile of the Section of the Paulista Railway Between Jundiahy and Cordeiro

The section selected for electrification presents a rather difficult profile, including maximum grades of 1.5 to 1.8 per cent. The approximate tonnage handled over the line from Jundiahy to Cordeiro during the year 1918 was 400,000,000 ton-km. or about 275,000,000 ton-miles, including freight, passenger and non-revenue service. The locomotives and substation are designed to handle approximately double this amount. As a basis for estimates it was assumed that the number of trains per day over the initial electric zone will be six passenger and twenty-one freight trains in each direction, making a total of fifty-four per day.

metric tons on the maximum 1.8 per cent grade at speeds from 19 to 26 km. (12 to 16 miles) per hour. The maximum allowable speed on tangent level track is 48 to 56 km. (30 to 35 miles) per hour. It is expected that because of the greater capacity and higher speed characteristics the electric locomotives will provide an appreciable improvement in the existing steam service, both as regards schedule speed and weight of trains handled.

The freight locomotive has a running gear consisting of two 2-axle trucks coupled together by an articulated joint, and a single cab of the box type. The draft gear is mounted on the trucks and all hauling and buffing stresses are transmitted through the truck frames and articulated joint, thus eliminating any possibility of damage to the cab and platform structure. Each truck is equipped with two 120-h.p. motors of the box-frame type geared to the driving axle by two sets of gearing, one at each end of the motor. One of the trucks is side equalized and the other cross equalized, thus providing the equivalent of a three-point support for the superstructure. The diameter of the driving wheel is 42 inches and that of the cast wheel center 36 in. allowing for a steel tire 3 in. in thickness. The overall length of the locomotive is 39 ft. 2 in. and the rigid wheel base 8 ft. 8 in. The interior of the cab is divided into three compartments by partitions or bulk heads so placed as to form two end compartments about 5 ft. in length for the operator's cabs and the remainder for housing the control equipment, compressor-exhauster set, and other auxiliary apparatus. The two pantograph trolleys are of the double-pen sliding type similar to that used on other heavy electrification projects and are mounted on the cab roof. These are insulated for 3000 volts and are designed to operate through a range from 15 to 22 ft. above the rail.

To conform to the equipment on this road it is necessary to provide control for the vacuum type brakes used on the cars. Two entirely different systems of brakes are therefore provided: a straight air brake system for the locomotive, and vacuum type brakes on the train. The two systems are manipulated in the same manner as the usual all compressed air type, the locomotive brakes being applied automatically at the same time as the train brakes under normal running. Brakes can be applied on the locomotive alone or on the train alone if desired. When regenerating, however, there is a magnet valve so arranged that straight air cannot be applied. However, should an emergency application be made, regeneration is discontinued and the brakes are applied on the locomotive.

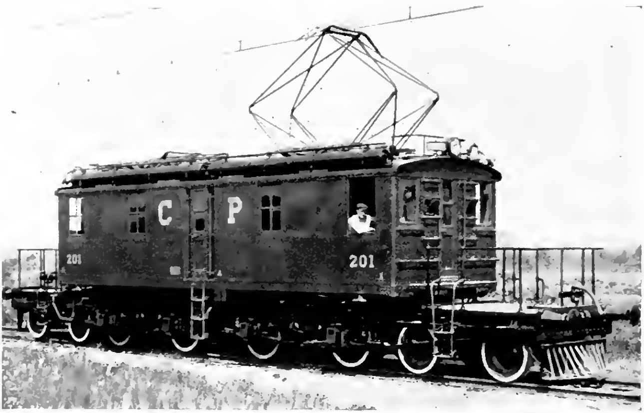


Fig. 3. One of the Four 120-ton Geared Passenger Locomotives

Motors

The motors are of the box-frame commutating-pole type designed for self ventilation. This feature is made possible by the increased room due to the wide gauge. In order to supply clean air for ventilating the motors, a ventilating pipe is provided and reaches to the outside of the locomotive truck. The fan is of the multiple type made integral with the armature head flange on the end opposite the commutator. Air is taken into the frame at the commutator end through a screened opening and divides into two streams, one passing over and around the armature and field coils, while the other is drawn through longitudinal ducts in the armature core. All of the air is expelled from the frame at the end opposite the commutator. These motors are designed for operation at 1500 volts per commutator with two motors connected permanently in series for the 3000-volt supply. The gears are of the forged steel type with a reduction of 82 to 18 or 4.56.

Control

The control equipment is of the well known type M designed for non-automatic single-unit operation of the locomotives. All contactors, rheostats, transfer switches, and the reverser are located in the central compartment of the cab. The master controllers, brake control, sander control, pantograph and other control devices are in the operator's cabs at the ends of the locomotive.

Energy for operation of the control is obtained from a 65-volt generator which is a part of the compressor-exhaustor unit. A 65-volt storage battery is connected in parallel with the generator to maintain constant voltage and to supply auxiliary lighting when the set is not running.

The motors may be operated all four in series through 14 steps of resistance, and with two motors in series and two groups in parallel through 10 steps of resistance. Regenerative braking is provided for returning energy to the line on descending grades. Ten steps are used for the regenerative braking control. The lighting and miscellaneous equipment includes the necessary lamps, switches, fuses, and wiring for illuminating the cab and for headlights and accessories. The headlights are of the incandescent type with side number plates and are supplied from the 65-volt generator or battery. Speed recorders are included as a part of the locomotive equipment. The draft gear is attached to the end frames of the trucks and is of the usual European type. The compressor-exhauster set is a combined unit having a compressor with a total piston displacement of 48 cu. ft. of air per minute at a pressure of 90 lb. per sq. in., an exhauster with a displacement of 150 cu. ft. of air per minute, and the 65-volt direct-current generator mentioned. The unit is driven by a 3000-volt direct-current motor operating from the trolley circuit.

Passenger Locomotives

The passenger locomotives are similar in design to the freight units except that a two-axle guiding truck is provided at each end to comply with the railway company's specifications for high-speed service. The motors used are identical to those on the freight locomotive except for the change in gear ratio to provide for maximum speeds

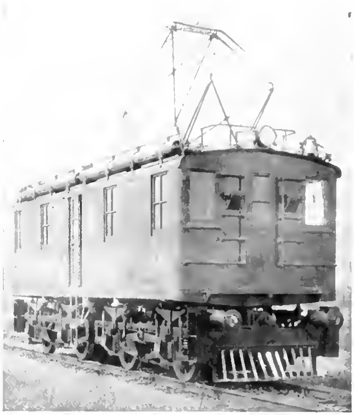


Fig. 4. One of the Eight 100-ton Freight Locomotives

from 90 to 100 km. (56 to 62 miles) per hour. The running gear consists of two 2-axle driving trucks, the inner ends of which are connected by an articulated joint. The outer ends are extended and supported on the guiding trucks by roller centering devices over the front axle and an articulated joint over the rear axle which also connects the guiding and motor trucks. The general arrangement of motors and control is the same as that on the freight locomotives, and a similar system of regenerative braking is also provided. These locomotives are designed for hauling a train of 400 metric tons trailing up a one per cent grade at a speed of 62½ km. (39 miles) per hour. The gear ratio on the passenger locomotive is 70/30 or 2.33.

For speeds above the full series and full parallel connections, a shunted field connection is provided by means of which the field current is reduced for maximum speed running.

Regenerative braking is accomplished by connecting one motor in such a way that it excites the field of the three other motors and also its own field. This scheme is in general similar to that used on the Chicago, Milwaukee

& St. Paul gearless passenger locomotives and eliminates the necessity for a separate motor-generator set for excitation. A balancing resistance is connected in the circuit to protect the motors against sudden surges of the line voltage and to give effective protection against line voltage changes. In order to begin regeneration, the main controller handle is turned to the first notch series position and the selective handle to the braking position. The main handle is then notched up until the desired braking effect is obtained.

As on the freight locomotives, a high-speed circuit breaker is placed between the 3000-volt trolley and the locomotive apparatus. The duty of this breaker is to protect the motors and equipment from any injury due to short circuits or excessive overloads. In such cases this breaker cuts in a protective resistance and then opens the line contactor. The action is very rapid so that the possibility of damage is reduced to a minimum. Breakers of a similar type are in operation in many parts of the United States both on locomotives and in substations.

Table I gives the dimensions, capacity, and weights of both the freight and passenger locomotives.

SUBSTATIONS

For the initial electric zone between Jundiahy and Campinas, one substation is being installed located at Louveira a distance of 15.3 km. (9.5 miles) from Jundiahy. This station contains three 1500-kw. 3-unit synchronous motor-generator sets, each arranged to operate its two generators in series for 3000 volts. Power is received from an 88,000-volt 60-cycle transmission line and stepped down through three 3-phase 1900-k-va. transformers to 2300 volts for the synchronous motor.

Transformers

The three-phase oil insulated and oil-cooled transformers are rated 60 cycles, 1900 kv-a., 41,500Y 88,000Y-2300 volts. The tanks are of steel plate with all joints welded. Four separable steel radiators are mounted on the outside of the tank to provide sufficient radiating surface.

Each transformer is provided with an oil conservator or auxiliary tank mounted on the cover. This device permits the main tank to be completely filled with oil and differences in volume of oil due to temperature changes take place entirely within the conservator. This arrangement prevents the condensation of any moisture within the transformer and such condensation as may occur in the conservator is collected in a sump, is indicated on a gage glass, and may readily be drawn off through a pet cock. Since there is no air in the main tank above the oil, there is no possibility of explosion due to ignition of gases formed from hot oil. The guaranteed efficiency of these units at normal load is 98.3 per cent.

Four 2½ per cent taps are provided in the low-voltage winding to compensate for variation in the transmission line voltage and 50 per cent starting taps are also provided for starting the motor-generator sets.

Motor-generators

The motor-generator sets are especially adapted to handling heavy railroad service and are substantially similar to those furnished for heavy electric railroad work in

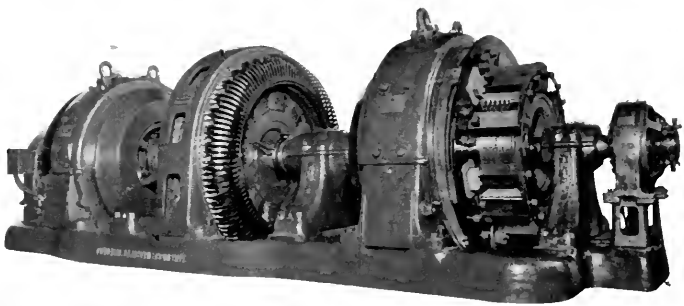


Fig. 5. 1500-kw., 3000-volt, Direct-current Motor-generator Set. Three of these are being installed in the Louveira substation

the United States. The generators are designed for 1500 volts per commutator and are permanently connected in series for 3000-volt operation. They are separately excited from a 125-volt direct-current exciter mounted at one end of the set. The series field is designed to provide flat compounding from no load to 150 per cent load. They are equipped with commutating poles and compensated pole-face windings to insure sparkless commutation at all loads. A load of three times normal rating can be carried for five minutes without injury. Under tests made before shipment, loads from five to six times normal were carried without sparking. All of the fields of both generators are connected to the low side to reduce the possibility of injury from high voltage. A simple form of flash barrier is provided for the commutators similar to that supplied on other high-voltage direct-current machines.

The synchronous motor is excited from a second 125-volt exciter direct connected to the opposite end of the set. This exciter carries a compound winding excited from the main 3000-volt conductor so that the motor field excitation varies in proportion to the load on the set. This provides for the proper excitation to give correct power-factor with varying loads and also insures stable operation under heavy overloads. The equipment is designed for inverted operation to take care of reverse power in cases of regeneration.

Switchboard

The switchboard is similar in design to those for other 3000-volt direct-current equipment. The 3000-volt panels are installed together with the auxiliary station lighting panel. There is one high-voltage panel for each motor-generator set, and one for each outgoing feeder. The main circuit breakers are located above and to the rear of the switchboard panels so as to be well out of reach to prevent accidental contact. They are remotely controlled from operating levers located on the front of the panels. A 3000-volt line switch is also included with each circuit breaker. These switches are also remote controlled from the front of the panel, as a safety measure. The switch handles for the circuit breakers are inverted to distinguish them from the line switches. The alternating-current switchboard is electrically controlled throughout. For lightning protection a 96,000-volt aluminum-cell arrester is installed in the high-tension room of the station.

As a protection against short circuits and excessive overloads a high-speed circuit breaker is installed with each motor-generator set. This is connected to the negative terminal of

TABLE 1

DATA ON ELECTRIC LOCOMOTIVES FOR PAULISTA RAILWAY

Type Locomotive	Freight	Passenger
Length overall	39 ft. 2 in.	55 ft. 0 in.
Width	10 ft. 1¼ in.	10 ft. 1¼ in.
Height overall with trolley down	14 ft. 3 in.	14 ft. 3 in.
Total wheel base	26 ft. 8 in.	46 ft. 0 in.
Rigid wheel base	8 ft. 8 in.	7 ft. 9 in.
Total weight	200,000 lb.	240,000 lb.
Weight on drivers	200,000 lb.	160,000 lb.
Weight per driving axle	50,000 lb.	40,000 lb.
Weight per guiding axle	None	20,000 lb.
Weight of mechanical equip.	115,400 lb.	155,400 lb.
Weight of electrical equip.	84,600 lb.	84,600 lb.
Diameter of drivers	42 in.	42 in.
Diameter of guiding wheel		36 in.
No. motors	4	4
Gear ratio	82/18	70/30
Total continuous rating, h.p.	1600	1600
Total (1 hr. rating) h.p.	1680	1680
Tractive effort cont.	28,820 lb.	14,720 lb.
Tractive effort 1 hr.	30,600 lb.	15,680 lb.
Speed continuous rating, m.p.h.	21 (34 km.)	41.25 (66.4 km.)
Speed 1 hour rating, m.p.h.	20.8 (33.5 km.)	40.5 (65 km.)
Maximum safe speed	28 (45 km.)	53 (85 km.)
Tractive effort, 30 per cent coef. adh	60,000 lb.	48,000 lb.

the machine and is arranged to connect a limiting resistance into the circuit upon opening. At the same time the station circuit breakers are opened, completely cutting off the power supply. The speed of these circuit breakers is such that resistance is inserted in the circuit before the short circuit current reaches a value sufficient to injure the apparatus. Other auxiliary equipment supplied to the station includes a 15-ton hand-operated crane, a portable oil filter press and oil testing equipment, and a stationary compressor set. For control current a $4\frac{3}{4}$-kw. battery charging motor-generator set is used with a 170-volt storage battery.

Fig. 6. Electrically Operated Switchboard for Controlling the Incoming Alternating-current Power

HIGH-TENSION TRANSMISSION LINE

The Railway Company's high-tension transmission line has been constructed with duplicate circuits mounted on separate wood poles between Jundiahy and Louveira, a total distance of 16 km. (10 miles). At Jundiahy this line is permanently tied in with a new line constructed by the Sao Paulo Light & Power Co., extending a distance of about 27 km. (17 miles) to the hydro-electric station at Parnahyba. The Power Company's line is constructed with an H-type pole line carrying the duplicate circuits. This transmission line from the water-power plant to the substation will thus be operated over a distance of 43 km. (27 miles) as a single system at 88,000 volts, 3 phase, 60 cycles. The line is designed for ultimately supplying three substations and the conductors are of 1/0 B.&S. stranded copper which will insure a very low line loss under ordinary operating conditions. On

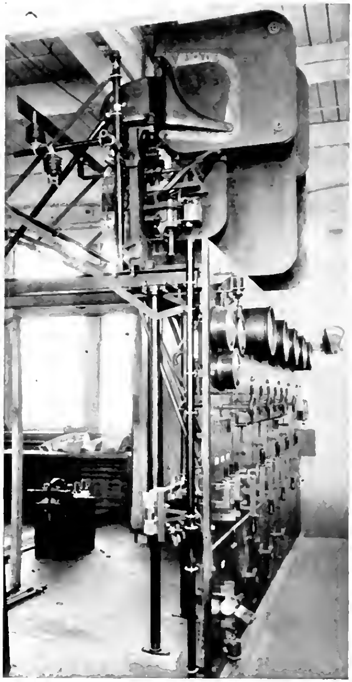


Fig. 7. 3000-volt, Direct-current Switchboard with Main Circuit Breakers Above

the Railway Company's line two cross arms are used with large pin type insulators. A ground wire is also carried on each transmission line for lightning protection.

SECONDARY DISTRIBUTION

The overhead line construction is of the same general design as that used on the Chicago, Milwaukee & St. Paul Railway. This is known as the twin catenary construction having two 4/0 trolley wires supported from the same steel messenger by loop hangers. Wood poles suitably guyed are used for supporting the catenary. The hangers for the two contact wires are attached at alternate points thereby giving a most flexible type of construction and insuring the elimination of all "hard spots." The use of the twin catenary construction is particularly successful for lines operating heavy trains requiring the collection of large amounts of current through pantograph trolleys. In addition to the advantages of the two contact wires for handling the current required, this construction also insures practically sparkless commutation at the point of contact, both for heavy freight and high-speed passenger operation.

Bracket supports are used on single-track construction and cross span for multiple-track work. The normal height of the contact wire is 21 ft. above the rail. For all sidings and yard tracks a single wire is used over each track.

LOCOMOTIVE TESTING AND SHIPMENT

In the preparation of the electric locomotives for testing and for export shipment there are a number of unusual features which may be of interest. The track gauge on the Paulista Railway being 63 inches, special arrangements were necessary to provide for removing the locomotives from the shop to the test track and other arrangements were necessary to provide the necessary test track. For this purpose about one mile of extra rail was laid on the East Erie Commercial Railroad with 63-in. gauge. In order to transport the locomotives from the shops to this track, a distance of about three-quarters of a mile, special transfer trucks were used; one for each truck of the locomotive. By means of these trucks, which operate on their own wheels of standard gauge, the locomotives were moved out over the usual transfer table and standard gauge track to the special gauge section provided for testing. Upon reaching this section they were moved off the transfer trucks over a ramp, the end of which was elevated to the same height as the special trucks.

A complete set of tests is run on all locomotives including regenerative braking and high-speed running. After test the locomotives are disassembled and prepared for export shipment. The cab complete is removed from the truck and the pantograph, bells, etc., removed from the cab roof. Each truck is shipped separately without removing the motors from the truck frame. In the case of the passenger locomotive, each bogie truck is shipped with the adjacent motor truck without disassembling. On account of the large vessels available for making this shipment it was not necessary to reduce the locomotive to such small packages as was the case with the Bethlehem, Chile Iron Mines Co. locomotives.

Industrial Applications of Local Heating with the Pyrotip

By E. A. Wagner
Fort Wayne Works, General Electric Company

The heating device described in this article provides a ready means of locally applying heat in many manufacturing and trade processes. The heat is generated at the tip of a carbon rod and is transmitted by conduction to the material which it is desired to heat; it is produced by the resistance of the carbon tip to the passage of the electric current and not by the formation of an arc, as the voltage is not sufficiently high to generate an arc. The pointed tip permits of exact application of the heat. The temperature can be controlled to suit the requirements by adjusting the length of the carbon rod between tip and holder. The more common uses of this device are illustrated.—Editor.

In practically every line of manufacture some means of local heating is required for various operations. The most common form is the gas flame, using illuminating gas with or without compressed air. In fine work, as in jeweler shops, the alcohol lamp and blow torch are used. For portable work the gasoline blow torch is commonly used. For more intense heat the oxy-acetylene flame is employed, as well as the electric arc, using either carbon or metallic electrodes.

A convenient and economical method of local heating is obtained by using the Pyrotip, Fig. 1, which is the trade name given to a low voltage transformer that has been specially designed for work of this nature. The secondary of the transformer furnishes sufficient current to quickly heat up the point of an ordinary 5/8-in. carbon rod. The voltage is so low that an arc cannot be drawn, but the temperature of the carbon point can be varied through a wide range by simply altering the amount of contact surface at the end of the carbon.

The most evident field for this device is in the melting or joining of lead parts or terminals of storage batteries. Lead, unless a clean surface is obtained, cannot be readily melted with a soldering copper. Acetylene flames or illuminating gas, enriched with oxygen, are most commonly used. These methods require the shipment of gas tanks and the maintenance of one or more tanks in reserve. They are objectionable on account of the open flame, which always is a fire and explosion hazard. Also the flame must be kept going when the operator is busy, so that only a small portion of the consumed gas is actually utilized in performing work.

Fig. 1. The Pyrotip—A Low Voltage Transformer for Applying High Temperatures Locally

With the Pyrotip current is used only when the operator is doing work, as the current in the secondary is automatically cut off when the carbon tip is lifted from the work.

Fig. 2 illustrates the binding post of a storage battery, ready to be built up, and Fig. 3 shows the same post after it has been built up, using the Pyrotip. One end of the secondary is grounded, and the operator holds the other end of the secondary, connected to a carbon electrode which he applies to the work.

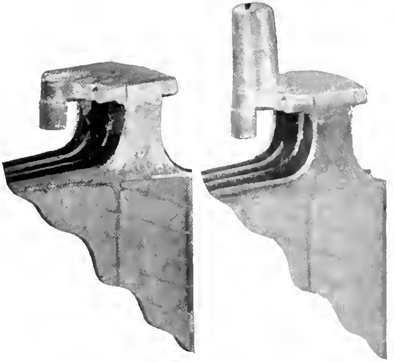
In the construction shown there is little or no danger to the operator from burning the eyes, as the operator when trained will avoid looking directly at the hot point. By working back of the carbon the eyes are shielded. Dark glasses are desirable in this work, although not so essential as with other forms of local heating, due to the ease with which the eyes can be protected by properly manipulating the holder.

The convenience of the portable equipment is illustrated in Fig. 4. It will be noted that the Pyrotip is carried and placed on a chair, and the operator is repairing the post in the battery while it still remains in the car. Operators have found the portability of the device of considerable value and convenience.

In jewelry stores a considerable amount of silver soldering is required in repairing broken silver spoons, gold rings, etc. The Pyrotip, utilizing a split or forked carbon electrode, is readily used. In this same line of work they have frequent need to melt down pieces of gold, silver, or platinum. The platinum works down in relatively small quantities, and it only takes a few seconds to melt down the platinum, whereas the gas ordinarily available requires a considerable length of time. It is also a simple proposition to utilize the same combination to melt down pieces of gold or silver from watch cases, putting them in small ingot form.

In the same way dentists can utilize the device for melting down old gold fillings, bringing them back to shape so that they can be used over again.

In a large manufacturing establishment a series of dangerous explosions of gasoline blow-torches used by the electrical wiremen resulted in the disposal of the blow-torches and the adoption of the Pyrotip. The workmen find they can do soldering more safely and quickly than with the old method. Matches are never required, and it is never necessary to go after gasoline or other fuel.



Figs. 2 and 3. Binding Post of Storage Battery Before and After Being Built Up by Pyrotip

In any machine shop a Pyrotip will be found of value in recovering hack saw blades. Hack saws frequently break one or two inches from the end. It takes less than a minute to burn a suitable hole at the broken end, making a shorter blade which can be used in an adjustable frame. Fig. 5.

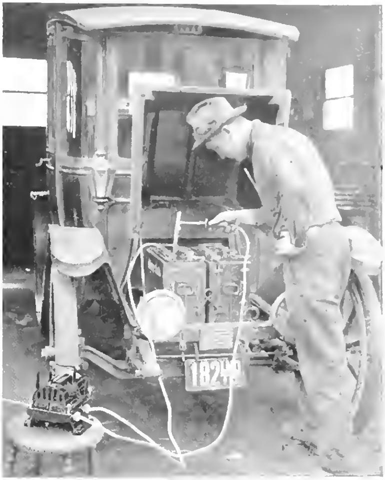


Fig. 4. Application of Pyrotip to the Repair of Vehicle Battery. The portability and general convenience of this device are valuable features for service of this sort

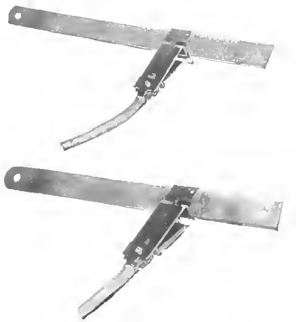


Fig. 5. Reclaiming Broken Hack Saw with the Pyrotip

In direct soldering, the hot point of the carbon tends to burn the tin in the solder. This does not happen where the solder is melted by the heating of an adjacent or inter-

[illegible]diate, as in soldering terminals on cables. Fig. 6 illustrates the operation of soldering cables into terminals.

For soldering work, where the operator must use the soldering copper without any

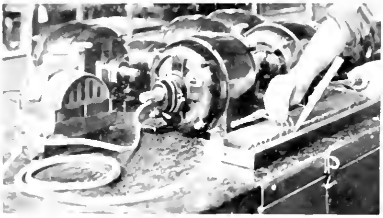


Fig. 6. Use of the Pyrotip for Soldering Cables and Terminals

attachment or as a detached heated copper, that is, where cable attachment is undesirable, the Pyrotip can be easily used, making use of the same principle of heating the soldering copper from the hot carbon point. Fig. 7 shows an ordinary soldering iron being heated without any cable connections to the soldering copper. It requires about two minutes to bring a heavy five-pound soldering copper up to suitable temperature for use. For a smaller iron, less time will be required. Small irons are required for such work as radiator repairs; heavier irons for work like tank work, or for washing machine tanks. For these combinations it is not necessary to purchase special soldering coppers. One big advantage of this method is that the clean tip, which is necessary for melting solder, is not brought to an excessively high temperature and burnt, as happens so readily when heating with a gas flame.

The actual temperature control, specially for lead burning, is easily accomplished by

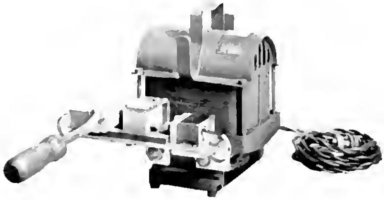
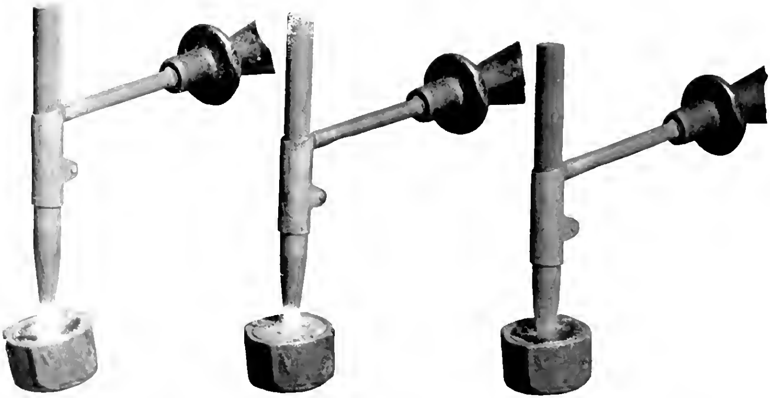


Fig. 7. Heating a Soldering Iron with the Pyrotip

altering the depth of submersion or surface contact at the carbon tip.

The point of the carbon, which is submerged in the lead, assumes approximately the temperature of the lead itself, which is only a little above the melting point of lead, 326 deg. C. Melting lead is difficult to superheat until the entire body has been melted. Just above the surface of the lead the carbon is much hotter. By comparison with a color chart it was found that with the point of the carbon submerged $\frac{1}{16}$ in. in lead, the temperature of the carbon just above the surface is about 1200 deg. C. (Fig. 8.) This temperature becomes gradually lower, but is not much below 1200 deg. C, $\frac{1}{4}$ in. back from the surface of the lead. (Fig. 9.) When the carbon is sub-



Figs. 8, 9 and 10. Showing Three Stages in the Application of the Pyrotip to Lead Burning for Storage Battery Work merged $\frac{1}{2}$ in. the maximum temperature of the carbon just above the surface of the lead is 700 deg. C. (Fig. 10). The greater energy put into the lead under these conditions is dissipated without leaving a high temperature because of the greater contact surface between the carbon and the lead. It permits the lead to carry off the heat and radiate it more rapidly. Probably under these conditions the lead is melted somewhat more rapidly, but not nearly in proportion to the amount of energy put in.

An incidental use of the Pyrotip for machine shop and tool room work is for the marking of tools, using a copper electrode. Tools are frequently marked by means of the acid or etching process, which requires considerable time. A copper pencil, used in place of the carbon tip with a suitable resistance ballast, enables the tools to be marked quickly and permanently.

From the description of the device it will be seen that it can be used to advantage for local heating in garages, battery repair stations, electrical repair shops, power stations, tin shops, radiator repair shops, jewelry stores, tool rooms, machine shops, etc., at a considerable saving in the cost of material and labor, and with increased convenience. It is possible for new operators, after a very short experience, to become quite skillful, and in various operations to exceed the quality and speed of the same work done by means of the gas torches.

Electric Applications in the Logging Industry of the Northwest

By E. P. Whitney

Portland Office, General Electric Company

The application of electric power to the logging industry is comparatively new, but the inherent advantages of electric drive will lead to the rapid extension of its use, if the cost of production is to be kept down to reasonable figures. The author gives statistics to prove the need of reducing the cost of production and analyzes these figures to show some of the savings that may be expected by electrification. He concludes his article with some notes on the electrical operation of the Snoqualmie Falls Lumber Company.—Editor.

The logging industry began in the Northwest in 1846, before the days of the electric motor, and when steam-driven machinery was not available in that region. The pioneers were handicapped by the lack of transportation facilities, having to depend upon man and animal power alone. These conditions imposed serious limitations on the distances over which logs could be hauled, as their average size was larger than the timber of the Middlewest and South.

These limitations confined logging operation to areas near the mills or to localities where steam or water transportation was available. Sometimes the mills were made portable so that they could be moved to the supply of commercially logable timber. Such timber was limited, and the available supply gradually became more remote from the mills. This led to the introduction of power logging machinery to maintain the balance between the cost of production and the prevailing market price.

The first steam logging engines were pigmies compared with the modern two-speed "yarder," capable of returning the empty line from the landing to the woods at a rate of about 2500 ft. per min., and of hauling logs back at about 1500 ft. per min. These logs are sometimes full length trees. Such speeds and powers are required because of the ever present race between production and costs.

Present Standing Timber

It is estimated that, to date, 129,000,000,000 ft. log scale have been cut in logging in the States of Oregon and Washington. This timber occupied 4,330,000 acres. There remains in Oregon and Washington 30,575,000 acres of commercial mature timber, including public and private holdings on which the stand is 745,000,000,000 ft. log scale of mature timber. About 58 per cent of this is privately owned.

The present rate of cutting in these two states is about $7\frac{3}{4}$ billion feet log scale per year, which denudes 260,000 acres of timbered land annually.

As other sections of the country are cutting out their available timber supplies, production in the Northwestern states is on the increase, so that each year sees the available timber stands recede farther and farther from today's transportation facilities. This requires elaborate and comprehensive logging operations to remove the logs from the site of their growth to the market centers.

Typical Scenes in Logging Operations in the Northwest. The economic possibilities for use of electric power are obvious. Lower righthand illustration shows No. 1 logs being split for fuel for donkey engine that is ordinarily employed for power. Because of this waste and the great amount of labor involved in splitting these logs this is an extremely expensive fuel. Electric power would entirely do away with this waste and expense

TABLE I

State or Province	Number of Operations	Number of Logging Railroads	Miles of Logging Track	Number of Locomotives	Logging Engines	Number of Men Employed
Washington	259	203	1864	420	1704	29,375
Oregon	150	93	930	220	814	13,479
California	67	52	739	153	445	11,888
Idaho	33	12	213	47	88	5,712
Montana	14	8	75	16	13	2,015
Arizona	6	5	138	13	2	695
New Mexico	8	5	112	18	0	600
Nevada	1	1	32	4	5	150
British Columbia	135	52	474	96	431	10,044
Total	538	431	4577	987	3502	73,958

Magnitude of the Northwest Logging Industry

Some idea of the magnitude of these undertakings may be obtained from Table I, a tabulation of recent statistics which covers 538 logging operations in the Pacific Coast States. It does not purport to be a complete compilation of all operations.

Operating Costs

Logging operating costs representative of 1920 conditions are divided as shown in Table II.

TABLE II

Division of Logging Operations	Per Cent Cost
Falling and bucking	11
Yarding and loading	24
Railroad and transportation	26.5
Rafting, booming, dumping, and towing boom sticks	4.5
Total operating cost	66
General and fixed expense	17
Stumpage	17
Total cost	100

Yarding and loading make up about 29 per cent of the total operating cost, neglecting stumpage, and are divided somewhat as shown in Table III.

TABLE III

Yarding and Logging Operations	Per Cent Cost
Labor (including labor in fuel handling)	16.6
Repairs	2.0
Fuel	1.2
Rigging trees	2.0
Haulage rope	4.9
Supplies	2.3
Yarding and loading (per cent total) operating cost)	29.0
Adding percentage of fixed charges and general expense chargeable to yarding and loading (neglecting stumpage)	6.9
Total yarding and loading (per cent total logging cost, excluding stumpage)	35.9

Stumpage costs are omitted in Table III because they are practically independent of the operating costs. Interest on the timber investment and timber carrying charges are included in stumpage. The item of fuel covers its value alone, and does not include the labor incidental to handling. Water cost for logging engines is included under general expense. These segregations are not by any means ideal, but will answer for the purpose in hand.

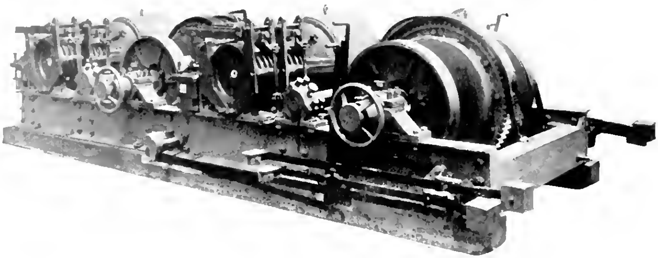
Yarding and loading costs are the most important among the total operating costs, being equalled only by the railroad and transportation cost. The items entering into yarding and loading costs are greatly affected by any scheme which will make labor more productive, reduce repair, supply, and auxiliary material costs, reduce depreciation and eliminate fuel and water costs. This, then, was the most logical place to begin the electrification of logging operations. The return, per unit of additional investment required, would apparently be greater for this part of the logging scheme than for any other single division of the work.

Of late, high fuel and labor costs have also directed attention to electrification of the logging railway. Should present fuel costs hold or advance, the saving which could be effected by operating logging railways with electric power is equally as large as for yarding and loading.

Water Supply for Steam Logging Engines

The obtaining of a water supply is often a very serious problem, and in every case requires an elaborate pumping and distributing system. Pumping stations, in turn, require attendance, a regular fuel supply and periodic inspection and repair. Should a pumping station fail for any reason, the log ging outfits depending upon it are forced to remain idle pending repairs, replacement or connection to some other source. Other sources are seldom available. Such stations are usually small or of moderate capacity with high heads, pumping fair distances sometimes one to two miles. They must be semi-portable, so that they may be moved from time to time as logging locations may require. The reasonable conclusion, therefore, is that such stations are not economical power users, and are expensive to operate and maintain.

The water distribution system is more or less complex and extensive, depending upon the availability of suitable water sources. In winter exposed distribution mains are subject to freezing, the alternative being to bury the main lines below the frost depth. It is variously estimated that water supply to the logging engines costs from 10 to 25 cents per thousand feet log scale. Available operating records show that few loggers have so favorable a location as to reach the lower figure.



Four-drum Duplex Loading Machine for Logging Operations
Snoqualmie Falls Lumber Company

Wood Fuel for Steam Logging Engines

The item of fuel requires more comment. Steam logging engines burn either split wood fuel or crude oil. A suitable log is selected from the fallen timber, hauled to the landing, and then swung into a convenient place for splitting near the engine. It requires more labor to place a log to be cut for fuel than to yard logs in normal operation. The logging engine is unproductive during this time, and the entire woods crew is doing no useful work.

The value of the log itself is usually neglected in keeping cost records. Loggers claim that valueless rotten or shattered logs are used for this purpose. This is far from the actual case, for rotten, shattered or knotty logs do not saw and split easily, also they do not burn as regularly as sound split wood, and therefore make firing more difficult and low steam pressure a more frequent occurrence. We therefore usually see the choicest of No. 1 logs being split up for fuel.

The actual value of the wood burned therefore includes:

(1) Stumpage value
(2) Falling and bucking costs
(3) Yarding cost plus the extra cost of placing in position for bucking
(4) Labor of wood buckers
(5) Cost of bucking supplies and materials
(6) Labor of fireman
(7) Profit which would have resulted from the sale of the log

Taking all of these items into consideration, one is forced to the conclusion that wood, as commonly supplied to logging engines, is an *extremely expensive fuel*.

From the point of view of conservation, the use of merchantable logs for fuel means the destruction of a natural resource that cannot be replaced or compensated for.

One extensive logging operation alone has come to the writer's attention, which in 1919 burned approximately 9,000,000 ft. log scale in its logging engines. This concern has a yearly average output of about 110,000,000 ft. in its mills, and assuming only one-half the fuel burned to have been merchantable logs, we still see that about 4 per cent of its yearly production was wasted beyond recall. Its operation has been going on for some fifteen years, and the timber holdings assure operations for twenty years to come. If the same ratio maintains, this one company will have destroyed natural resources (which in the particular case in question are passing only too fast and can never be replaced) equal to about one and one-half years continuous operation of their property. No one has derived the benefits that should have accrued from this timber.

Wood fuel for logging is an expensive luxury, and is justified only when it is the sole source of energy commercially available. there has been no recession of fuel oil price in the Northwest, and the oil companies have not been in a position to protect consumers, as regards price or supply, by contracts for future requirements. Purchases are therefore made in the open market. This is an unsatisfactory condition, because a logger must be assured of a regular fuel supply in order to plan operations economically. The users of oil fuel will therefore face an unsatisfactory condition until the situation materially improves.

Use of Tree Trunk for Handling the Yarder and Hoisting Cables for Hauling in Logs and Loading Them on Railroad Cars

Arrangement of Outdoor Transformer Equipment Showing Method of Mounting on Sled and Location Near Railroad Tracks

Oil Fuel for Steam Logging Engines

The use of oil fuel conserves the timber holdings. It eliminates the labor of wood buckers and firemen, and permits even firing and quick response to heavy load demands. It requires central storage, tank facilities, a system of distribution to the logging engines and moderate storage capacity at the logging engines. The other item of expense for oil is the cost of the fuel itself.

The total cost, using oil fuel, is usually considered to be slightly less than for wood fuel, but the fact that the use of oil and wood is so evenly divided among present operations indicates that local conditions are the determining factor.

The last year has seen a serious curtailment of crude fuel oil supplies, and a very large increase in its price. Up to the present

Electric Power for Logging Outfits

Electric installations have shown that operating speeds are maintained more closely throughout the period of haul-in than with steam. The available operating time is also increased. Repairs, adjustments, inspection, and periodic overhaul are greatly reduced. Sled vibration is reduced to a minimum, and sled life is correspondingly increased. Operating supplies for the engines and boilers are eliminated, and the indications are that haulage rope and rigging equipment are subjected to smaller periodic maximum strains and their useful life prolonged. The useful life of the machine equipment is materially lengthened; water costs for logging engines are entirely eliminated and fire hazard, due to the logging engines in the woods is reduced to a minimum.

Electric operation requires:

(1) A source of electric energy; viz., available service from a neighboring power system, or

An electric generating station reasonably near the logging scene

(2) Main transmission line from the source of energy to the woods

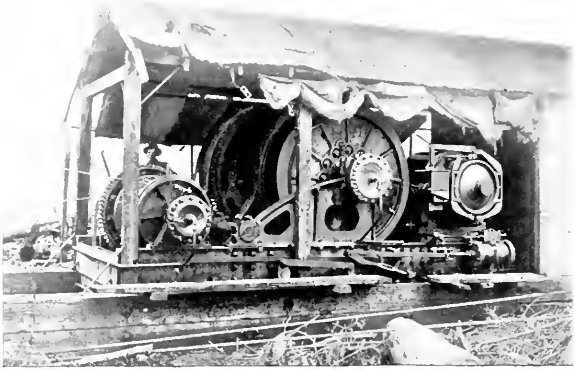
(3) Branch transmission lines to the several "sides"

(4) Motors for yarders and loaders, with suitable control equipment

Beyond the question of cost, none of these items adds any complications to the logging operations; and the matter resolves itself into a proper comparison of fixed and operating costs of the steam method and of the electric method. In every case that has come up for consideration the electric method has justified itself.

Of course a source of electric energy is necessary. A great many large loggers are also sawmill operators, and sawmills are as a rule reasonably near the timber; viz., from five to twenty-five miles from the most distant timber to be handled by the mill in question. The reason for this is evident. One thousand feet log scale weighs from 8000 to 9000 lb. When manufactured into lumber this log will give approximately 1150 ft. board measure (assuming 15 per cent overrun) which when green will weigh from 3400 to 3800 lb.

The loggers and mill operators naturally do not wish to haul this excess log weight any farther than necessary, particularly if a part of the haul must be outside their privately owned railways. So the sawmill is located as near the timber as appears to be commercially economical. But present-day stands of timber are receding farther and farther from large centers of population, and so such sawmills find no market for other than manufactured products, except by absorbing a long railroad haul. Cord and stove wood and surplus "hogged fuel" are simply a loss to them, because of prohibitive freight rates to a market, and consequently this excess refuse goes to a "burner."



Electric Yarder Installed at Potlatch Lumber Company, Elk River, Idaho

Sources of Electric Power

The wood refuse will supply more power than is required for the logging and railway operations, and if used to generate the necessary electric energy for them, the cost of such electric generation is low. This is the logical way to secure electric power for railway and logging needs.

There are many loggers who have no sawmill connection; and for such, if no electric power company line is near, the solution is to effect a working arrangement whereby a neighboring sawmill furnishes the power. The sawmill owner, who is probably also one of the logger's customers, will thus realize on some of his waste and the logger will secure electrical energy at a reasonable price.

If, however, a power company's line is reasonably near, within 10 or 15 miles of the logging operation, the purchase of power from that company will almost always be the most economical proposition.

The cost of such electric energy is a consideration of course, but all rates prevailing in the Northwest will permit a logger to purchase power and show a considerable saving.

Electric Power Distribution

The next two factors, viz., the main transmission line to the camp and the branch lines to the "sides," are functions of the location of the timber. The general statement may be made that a one "side" operation can afford to build a transmission line a distance of seven to ten miles, purchase electric energy at approximately 1½ cents per kw-hr., purchase transformer substations for the power end and for the logging end of the line, and show a justifiable saving over steam operation using either oil or wood fuel. This is the most disadvantageous type of operation. As the size is increased, and consequently the number of logging engines used, the saving of electric operation increases very rapidly, and the distance of the timber from the power source can be very much greater.

Motor Equipment for Logging Engines

The motor equipment and control for logging work have been developed as the result of a large number of test installations. The first was made about 1911. All have been successful in their particular field and have justified all expectations as to performance and economy.

Building upon the data and experience gathered, the first comprehensive electric logging installation was decided upon in 1916. A more inauspicious time could not have been chosen, and delay after delay was necessarily submitted to, until in October, 1918, the first yarder in the fir district began commercial operation. In the interval between 1916 and 1918 the fundamental scheme of logging had undergone a radical change, and there was a further delay to early 1920 before the first "side" was completed by the addition of an electric duplex loader.

All of the electrical equipment is of extra rugged design, and is weatherproofed to permit its installation on sleds which must expose it more or less to the elements. The operating characteristics of both motors and control most suitable to logging requirements are secured by special design, as a result of earlier tests, and the latest outfits will embody the desirable features which have evidenced themselves during the two and a half years continuous operation just completed.

The following is a brief extract from the history of the operation of this pioneer electric installation in the fir district, and tells of the experience of the Snoqualmie Falls Lumber Co.*

Logging Operation of the Snoqualmie Falls Lumber Co.

"The logging operations of the Snoqualmie Falls Lumber Company consist of two camps of three "sides" each and about forty miles of railroad, including main line and spurs.

"One of the six sides has been completely electrified. The yarder began operation in October, 1918. The arrangement of the original gearing of this machine produced a main line speed of only 300 ft. per min., and during 1918 and early 1919 the transformers in the line serving this installation were of insufficient capacity. However, this yarder has shown results (outputs) equal to the steam outfits working in the same kind of timber.

"The electric machine was originally built for ground yarding work, the adopted line speed for such work being about 300 ft. per min. Before it was put into operation, high-lead yarding had become standard practice. The line speed for high-lead work is considerably faster than for ground yarding, so that the machine as first operated on the high-lead system had a maximum line speed considerably lower than the speed of the steam outfits in the same camp. It is interesting to note that, in spite of the lower maximum line speed, the production of the electric outfit was equal to that of the steam outfits.

"During 1918 this machine yarded 3,144,-898 ft. of timber in 44 days, from 64 acres, in two settings, averaging 71,470 ft. per day. In 1919 the same outfit, with the same maximum line speed but with added transformer capacity, yarded 18,403,339 ft. in 10 settings, covering 350 acres, an average of 77,000 ft. per day. This was a little better showing than the steam outfits made in 1919 in the same vicinity.

*From paper by R. E. Gray, presented at the 11th Pacific Logging Congress, 1920.

"During 1920, up to July 1, the electric side has fallen below the 1919 average, but this is due entirely to the timber, the average log for 1920 falling far below the average of 1919. The total yarded from January 1, 1920, to July 1, 1920, was 9,169,185 ft. in 133 working days.

"A resume of the period from October, 1918, to July 1, 1920, shows:

Number of days operated	416
Number of settings	18
Acres logged off	572
Total log scale	30,717,422 ft.
Average per day	73,842 ft.

"During this time no failure of the motor or control equipment has resulted in any lost time. The upkeep is very small, and no repairs have been required in the two years.

"This side has demonstrated that logging can be done economically by using electricity as motive power. The cost of operation has been lower than with the steam outfits.

"This company generates power at its sawmill. The plant is about six miles from present logging operations, and will ultimately be about twenty-five miles away when the farthest timber limits are reached. The present transmission voltage is 13,200 volts, but during 1921 this will be increased to 22,000 volts, at the time of adding the higher powered two-speed yarders and loaders. The main line generally follows the railroad right-of-way and is of permanent construction, using cedar poles and steel pins, but for the temporary lines to spurs, etc., which are to serve only for about a year before being taken down and installed elsewhere, anything in the shape of a pole or small tree that happens to be in line is cross-armed and used. Locust pins are used on the temporary lines. Suitable line disconnecting switches are provided to permit work on extensions to existing stub lines without interruption to service.

"These lines lead directly to outdoor step-down transformer stations near each logging outfit. The logging motors are designed for 550 volts. The individual woods transformers are of special electrical design to withstand the heavy loads to which they are subjected from time to time, and are of rugged mechanical design to render them suitable for frequent transportation to new locations.

"Careful operating records have been kept of the electric logging outfits, and the direct operating savings have been greater than predicted, fully justifying the change from steam logging engines. The camps of the Snoqualmie Falls Lumber Company will be fully converted to electric operation by the latter part of 1921, and as other loggers become more familiar with the possibilities of the electric method, greater and more rapid advances in this new application may be expected."

Ventilation of Large Motor Room of the Tata Iron & Steel Company, Jamshedpur, India

By C. B. Huston

Power and Mining Engineering Department, General Electric Company

Forced ventilation, even under average conditions in our own country, is a necessary factor in the operation of most large electric motors, generators, etc., but the conditions that must be taken into account in the ventilation of the motor room of the Tata Iron & Steel Company are extremely unusual as regards temperature, humidity and capacity of apparatus installed. Exactly what these conditions are is described by the author. A short calculation is made to determine the quantity of air that is required to limit the rise in temperature, and recommendations are given respecting the arrangement of the air ducts in an installation of this kind, which are also extended to include the air conditioning equipment.—Editor.

Ventilation is one of the major problems in the design of any large power station. The success of the electrical apparatus will depend primarily upon the effectiveness of the ventilating system in conveying away the losses of the machines, consequently any installation requires to a greater or lesser degree some consideration of this question.

Perin & Marshall, Consulting Engineers, New York, who have been associated with the entire development since its inception, are designing the motor station of the blooming and combination rail and structural mills of the Tata Iron & Steel Company, Jamshedpur, India. The principal problems in the consideration of the ventilation of this station are made the subject of discussion in this paper. Ventilation in this case is of special importance for the following reasons: first, the particular location of the station with respect to the mills: second, the capacity of the apparatus, and, third, the climatic conditions of the country.

The station building, which is 75 feet wide by approximately 360 feet long, is necessarily very large because of the nature of the apparatus which it accommodates. On account of serving both the blooming mill and the combination rail and structural mills, it is located directly between the two. In addition, the soaking pits extend across one end and the cooling beds across the other. Consequently the station is entirely surrounded by a hot and dirty mill atmosphere. Except for the extension of the walls above the mill structures in which louvers or windows will be constructed, the station must be made as air tight as possible. The conditions therefore require a forced ventilation system supplying fresh air.

There is little dispute as to the merits of the air washer. Such apparatus has established its importance for use in all systems of ventilation. Not only is the air freed from particles of dust, but advantage may also be taken of humidification to lower the temperature of the air. Thus by means of blowers clean cool air may be forced into the station and the warm air allowed to escape through ventilators at the roof. This method not only affords a ready means of control and distribution of the air, but also builds up a counter pressure within the room which tends to keep out the mill dust due to the outward leakage through all cracks and openings. The problem is thus resolved into two factors, first, the quantity of air, and second, the distribution of the air.

Apparatus and Losses

The station will ultimately contain machines with losses in kilowatts as follows:

Apparatus	Losses
1 5600-h.p. d-c. reversing blooming mill motor	350 kw.
1 6000-kw. motor-generator consisting of three 2000-kw generators and one 4000-h.p. induction motor, and flywheel	650 kw.
1 6300-h.p. d-c. rail and structural mill motor	350 kw.
1 5000-kw. motor-generator consisting of two 2500-kw. generators, one 6500-h.p. induction motor, and flywheel	625 kw.
1 5000-h.p. (future) d-c. reversing roughing mill motor	350 kw.
1 4000-kw. (future) motor-generator consisting of two 2000-kw. generators, one 4000-h.p. induction motor, and flywheel	500 kw.
2 1500-kw. motor-generators consisting of d-c. generator and synchronous motor	300 kw.
3 control apparatus consisting of exciters, slip regulators and resistors for each of the mill equipments	450 kw.
3 pump and 1 compressor motor	100 kw.
Total losses	3675 kw.

The 5000-h.p. roughing mill motor and 4000-kw. motor-generator with their control will not be installed at present, but will be included in the calculation for ultimate air capacity of the ventilating system. The d-c. mill motors and motor-generators are rated upon the root mean square of the duty cycle which they are supposed to perform. Therefore the losses at the rated loads represent the heating to be dissipated for normal continuous duty. One 1500-kw. motor-generator will constitute a spare; consequently the station losses as tabulated above may be reduced to 3525 kw. as a total upon which calculations may be based.

The design of each d-c. mill motor is such that it requires forced ventilation. Since its armature is repeatedly reversing, there are intermittent periods when the windage is negligible. It therefore becomes necessary to force-ventilate them. All other machines are self-ventilating, that is, normally require no special supply of air. Therefore, with the exception of the d-c. mill motors, the problem becomes that of keeping the room temperature at a value low enough so that the apparatus will operate at a safe ultimate temperature.

Climatic Conditions

A study was made of the climatic conditions of the country and their effect upon the efficiency of the ventilating system. By referring to temperature and humidity charts published by the government of India, it was found that the extremes of temperature and humidity exist at different seasons of the year. The highest temperatures are reached in May near the end of the dry season. At this time the mean maximum temperature recorded among the data investigated was found to be 107 deg. F., at which time the humidity was not over 30 per cent. Later during the rainy season the temperature drops, but the humidity naturally rises. The extremes for the wet season are reached during August, when the maximum mean temperature of 90 deg. F. is obtained with a relative humidity of 85 per cent. The maximum average values, however, are shown to be 85 deg. F. with humidity at 65 per cent. During other seasons of the year the climate is quite moderate.

By referring to psychrometric tables the resulting wet bulb temperatures for the above conditions are as follows:

107 deg. F. at 30 per cent humidity—wet bulb 80 deg. F.

85 deg. F. at 65 per cent humidity—wet bulb 75.6 deg. F.

90 deg. F. at 80 per cent humidity—wet bulb 81.8 deg. F.

The average of these wet bulb temperatures is approximately 80 deg. F.

With the best air conditioning equipments, the air when passing through the washer becomes saturated and therefore is reduced to the wet bulb temperature. Further cooling cannot be effected without using large quantities of cold water, and since it is impracticable to supply it in this particular case, the wet bulb temperature must be taken as the minimum obtainable. Therefore the maximum temperature of the ventilating air as it enters the station may be considered to be not greater than 80 deg. F. This value will be used in the calculations to follow.

CAPACITY OF VENTILATING EQUIPMENT

1 kw-hr. loss = 3417 B.t.u.

1 kw-min. loss = 57 B.t.u.

The volume of air in cubic feet per minute to absorb 57 B.t.u. for 1 deg. F. rise is

$$\frac{57}{0.2375 \times 0.0736} = 3260 \text{ cu. ft.}$$

where 0.2375 is the specific heat of air and 0.0736 is the weight of one pound of air at 80 deg. F. Therefore for each kw. of loss there will be required 3260 cubic feet of air per minute per degree F. rise.

Neglecting radiation through the walls, which could only be slight, all losses of the machines will be dissipated as heat and absorbed by the air in the room. The warm air will rise and pass out through the openings at the top of the room at whatever rate (in cubic feet per minute) that the cool air is supplied. Assume that the outgoing air is to be kept to a maximum of 120 deg. F. Based upon incoming air at 80 deg. F. allows 40 deg. F. rise. Therefore the quantity of air required to absorb the losses of the station is

$$\frac{3525 \times 3260}{40} = 288{,}000 \text{ cu. ft. per minute.}$$

It is known from previous experience that each d-c. mill motor will require 50,000 cu. ft. of air per minute to assure its successful operation. On account of the inefficiency of the ventilation of such motors due to the short passage through them, only about three-fourths of the losses are absorbed by the air. The temperature of the air leaving each motor is

$$80 \text{ deg. F.} + \frac{0.75 \times 350 \times 3260}{50{,}000} = 97.1 \text{ deg. F.}$$

Thus 150,000 cu. ft. of air is delivered into the room through the three motors at 97.1 deg. F. The remaining quantity of air, 138,000 cu. ft., will enter at 80 deg. F. The resulting temperature of the 288,000 cu. ft. will be

$$\left[\frac{150{,}000}{288{,}000} \times 97.1^\circ \text{ F.}\right] + \left[\frac{138{,}000}{288{,}000} \times 80^\circ\right] = 88.9^\circ \text{ F.}$$

On the basis of 288,000 cu. ft. of air at 88.9 deg. F. the temperature of the outgoing air by the absorption of the remaining losses of the d-c. motors and the losses of the other apparatus will be

$$88.9^\circ \text{ F.} + \frac{[3525 - (3 \times .75 \times 350)] \times 3260}{288{,}000} = 120^\circ \text{ F.}$$

The air temperature at the floor station will be some mean between 88.9 deg. F. and

120 deg. F. depending upon circulation and eddy currents set up within the room and the location at which the temperature is measured. Since the machines are laid out on the basis of either 35 deg. C. or 40 deg. C. rise above room temperature, their ultimate temperatures will be between the limits of (40 deg. C.+88.9 deg. F.) and (40 deg. C.+120 deg. F.) that is, between 71.6 deg. C. as a minimum and 89 deg. C. as a maximun, depending upon the resulting room temperature.

It is therefore recommended that in order to obtain full rated output from the ultimate number of machines, during the hot and rainy season, air conditioning equipment capable of delivering 300,000 cu. ft. of air per minute should be installed.

Distribution of Air

As previously stated, the d-c. motors are constructed for forced ventilation, the magnet frames being encased to receive air underneath the machines. The motor-generators and other apparatus are standard open construction, but an effective means of supplying cool air to them is to discharge the air into a pit underneath them. Recommendations will not be given here upon the design of the air ducts. Their construction is greatly influenced by the machine and mill foundations. It may be stated, however, that insofar as is possible each machine should be served by a duct branching off of one main feeder. At each branch there should be a damper, by means of which the flow of air to each unit may be controlled. All ducts should of course be laid out with the least possible resistance to the flow of the air, which is accomplished by keeping the distances to a minimum, the cross section circular or a square rather than rectangular, the walls smooth, and all bends on a large or easy radius. Based upon a maximum velocity flow of 30 feet per second, the cross section of the main duct will be

$$\frac{300,000}{60\times60}=167 \text{ square feet.}$$

The air conditioning equipment should preferably be divided into three units each with capacity of 100,000 cu. ft. per minute. Two units should be installed at present and the third one added with the future d-c. mill motor and its motor-generator. With this arrangement the maximum benefit of the installation will be obtained.

The pressure required of the system cannot be specified inasmuch as this will depend upon the resistance in the ducts, but assuming this to be conservative, it is estimated that the blowers on each air conditioning equipment should develop from 3.5 to 4 in. water gauge.

INDUSTRIAL TEACHERS' SCHOLARSHIPS IN NEW YORK

The University of the State of New York is offering twenty-five scholarships to qualified trade and technically trained persons who desire to prepare themselves for teaching. Persons selected to hold these scholarships who satisfactorily complete the prescribed one year resident industrial teacher training course are licensed for life to teach their specific occupations in the vocational schools of the State. The salaries paid vocational teachers now range from $1800 to $3500 per annum.

Amount of Scholarship

Each holder of a scholarship will receive at least $1000 for the period of one school year. This amount is paid in ten equal installments.

Course and Attendance

Holders will be required to be in attendance for ten months in the Industrial Teacher Training Department of the State Normal School at Buffalo.

Qualifications of Applicants

Applicants for appointment to the industrial teachers' scholarships must possess the following qualifications:

1. *Trade, industrial or technical experience.* At least five years of successful all-round experience in work of not less than journeyman's grade in some trade, industrial or technical occupation.
2. *Education.* A good general education and ability to speak, read and write the English language.
3. *Age.* Not less than twenty-one or more than thirty-six years of age on August first of the year in which the appointment is made.
4. *Health and character.* Of good moral character and in possession of good health.
5. *Citizenship and residence.* A citizen of the United States and a resident for one year of the State of New York.

Selection of Scholarship Holders

On the basis of the qualifications of the candidate merit list will be set up for each trade, industrial or technical occupation. There will be no formal examination but candidates will be rated by examining committees as to general education, practical experience, loyalty, moral character and physical fitness. Candidates may be required to appear before the examining committees for a personal interview.

Occupational List for 1921

The twenty-five scholarships will be awarded to qualified persons with all-round experience in the following occupations:

Electrical construction, repairing and operating.
Machine shop work.
Automobile repairing.
Machine drafting and designing.
Architectural drafting and designing.
Sheet metal working.
Printing, including presswork and composition.
Bricklaying.
Painting and decorating.
Carpentry.

Information and Application Blanks

Detailed information and blanks upon which application for scholarships may be made should be secured very promptly. The Director of Vocational and Extension Education, State Department of Education, Albany, N. Y., will furnish this material and information upon request.

Watthour Meter Method of Testing Current Transformers for Ratio and Phase Angle

By J. R. Craighead and C. T. Weller

General Engineering Laboratory, General Electric Company

[illegible] method of testing instrument transformers for ratio and phase angle has received [illegible] of certain advantages which it possesses. Through its use, satisfactory com[illegible] obtained by careful testing; however, difficulties have been encountered by different [illegible] results. This is due to the large number of possible sources of error. The present [illegible] derived from a study of the method and includes detailed directions for testing, for [illegible] and for avoiding the chief sources of error. Formulas are given, covering all necessary [illegible] of the results. The procedure to be followed is similar for both potential and current [illegible] the directions given apply to the testing of current transformers as this is the more impor[illegible] of the method. An example of the application of the directions to an actual test is in[illegible].

Introduction

The watthour meter method of testing instrument transformers for ratio and phase angle was developed for testing transformers at the point of installation.

THE USE OF THE METHOD SHOULD BE LIMITED TO CASES WHERE ACCURACY IS ESSENTIAL BUT WHERE IT IS IMPRACTICABLE TO SEND THE TRANSFORMER TO A SUITABLE TESTING LABORATORY.

The method has the advantages of requiring but little special apparatus and of giving satisfactory commercial accuracy when properly applied.

THE ACCURACY OBTAINABLE BY CAREFUL TESTING IS WITHIN 0.2 PER CENT IN RATIO AND WITHIN 10 MINUTES IN PHASE ANGLE.

The method has certain disadvantages such as a large number of possible sources of error and the excessive length of time required for testing.

THE TIME REQUIRED FOR TESTING A CURRENT TRANSFORMER FOR RATIO AND PHASE ANGLE AT SIX DIFFERENT CURRENT VALUES WITH ONE SECONDARY BURDEN AT ONE FREQUENCY IS ABOUT SEVEN HOURS. THIS ESTIMATE IS BASED ON OBTAINING THE ABOVE GRADE OF ACCURACY WITH STANDARD WATTHOUR METERS.

Historical

The watthour meter method of testing instrument transformers for ratio and phase angle is the subject of technical paper No. 233, prepared by Dr. P. G. Agnew and published by the Bureau of Standards; this paper is republished in the Bulletin of the Bureau, Volume 11, No. 3. Dr Agnew's discussion is of a broad nature and omits many details essential to obtaining accurate results. The formulas used for determining phase angle are based on the so-called tangent formula.

After a careful study of the watthour meter method and its application, the detailed testing instructions given in the present article have been formulated. Formulas have also been developed for handling the results. The phase-angle formulas are based on the so-called cosine formula. This permits determination of phase angle from the standard tabulations (Tables I and II) for correction of wattmeter readings for phase angle.* Accurate test results may be secured by carefully following the instructions given, and the calculations are greatly simplified by the procedure outlined. A procedure similar to that for current transformers may also be followed for corresponding tests on potential transformers.

General Description of Method

The watthour meter method consists in determining, from readings of watthour meters connected in the secondary circuit, the difference in ratio and phase angle between two current transformers of the same range whose primary windings are connected in series; or between two potential transformers whose primary windings are connected in multiple. The constants of one transformer, which is used as a standard, are known and the constants of the transformer under test are thus determined in terms of the constants of the standard transformer. Readings are taken at unity power-factor to obtain difference in ratio and at low power-factor to obtain difference in phase angle. The meters are interchanged to eliminate any difference in their rates.

The errors of the method are within 0.2 per cent in ratio and 10 minutes in phase angle. To secure this accuracy, a competent

* [illegible] L. T. R[illegible] [illegible] the A.I.E.E., [illegible]

TABLE I

CORRECTION FACTORS FOR PHASE ANGLE $\left(\frac{\cos\theta}{\cos\theta_2}\right)$

Use With Lagging Load With $(\alpha+\beta+\gamma)$ Positive
Use With Leading Load With $(\alpha+\beta+\gamma)$ Negative

$\alpha+\beta+\gamma$	APPARENT POWER-FACTOR $\cos\theta_2$ 0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90
5′	0.9855	0.9904	0.9928	0.9943	0.9953	0.9966	0.9974	0.9980	0.9985	0.9989	0.9993
10′	0.9710	0.9808	0.9857	0.9887	0.9907	0.9933	0.9949	0.9961	0.9970	0.9978	0.9985
15′	0.9565	0.9712	0.9786	0.9831	0.9860	0.9899	0.9924	0.9941	0.9955	0.9967	0.9978
20′	0.9420	0.9616	0.9714	0.9774	0.9814	0.9866	0.9898	0.9922	0.9940	0.9956	0.9971
25′	0.9276	0.9520	0.9643	0.9718	0.9768	0.9832	0.9873	0.9902	0.9925	0.9945	0.9964
30′	0.9131	0.9424	0.9571	0.9661	0.9722	0.9799	0.9848	0.9883	0.9910	0.9934	0.9956
40′	0.8841	0.9232	0.9429	0.9548	0.9629	0.9732	0.9797	0.9844	0.9880	0.9912	0.9942
50′	0.8552	0.9040	0.9286	0.9436	0.9537	0.9665	0.9747	0.9805	0.9850	0.9890	0.9928
1°	0.8262	0.8848	0.9143	0.9323	0.9444	0.9598	0.9696	0.9766	0.9820	0.9868	0.9914
10′	0.7971	0.8655	0.8999	0.9210	0.9350	0.9530	0.9645	0.9726	0.9789	0.9845	0.9899
20′	0.7681	0.8463	0.8857	0.9097	0.9257	0.9463	0.9594	0.9687	0.9759	0.9822	0.9884
30′	0.7393	0.8271	0.8713	0.8984	0.9164	0.9396	0.9543	0.9647	0.9729	0.9800	0.9869
40′	0.7101	0.8079	0.8570	0.8872	0.9071	0.9329	0.9491	0.9608	0.9699	0.9777	0.9854
50′	0.6811	0.7887	0.8427	0.8759	0.8978	0.9261	0.9440	0.9568	0.9668	0.9755	0.9839
2°	0.6521	0.7695	0.8284	0.8646	0.8885	0.9194	0.9389	0.9529	0.9638	0.9732	0.9824
10′	0.6230	0.7502	0.8140	0.8531	0.8791	0.9126	0.9337	0.9488	0.9607	0.9709	0.9808
20′	0.5940	0.7309	0.7996	0.8417	0.8697	0.9058	0.9286	0.9448	0.9576	0.9686	0.9793
30′	0.5649	0.7116	0.7853	0.8303	0.8604	0.8990	0.9234	0.9408	0.9545	0.9663	0.9778
40′	0.5359	0.6924	0.7709	0.8189	0.8510	0.8922	0.9183	0.9368	0.9514	0.9640	0.9763
50′	0.5068	0.6731	0.7566	0.8074	0.8417	0.8855	0.9131	0.9328	0.9483	0.9617	0.9748
3°	0.4778	0.6538	0.7422	0.7960	0.8323	0.8787	0.9080	0.9288	0.9452	0.9594	0.9733
10′	0.4487	0.6343	0.7277	0.7845	0.8228	0.8718	0.9028	0.9247	0.9420	0.9570	0.9717
20′	0.4196	0.6148	0.7133	0.7731	0.8134	0.8650	0.8976	0.9207	0.9389	0.9547	0.9701
30′	0.3906	0.5953	0.6989	0.7617	0.8040	0.8582	0.8924	0.9166	0.9358	0.9523	0.9685
40′	0.3615	0.5759	0.6845	0.7503	0.7946	0.8514	0.8871	0.9126	0.9327	0.9500	0.9670
50′	0.3325	0.5564	0.6701	0.7388	0.7852	0.8445	0.8819	0.9085	0.9295	0.9476	0.9654
4°	0.3034	0.5369	0.6557	0.7274	0.7758	0.8377	0.8767	0.9045	0.9264	0.9453	0.9638
10′	0.2743	0.5177	0.6412	0.7159	0.7663	0.8308	0.8714	0.9004	0.9232	0.9428	0.9621
20′	0.2452	0.4985	0.6268	0.7045	0.7569	0.8239	0.8662	0.8963	0.9200	0.9404	0.9605
30′	0.2161	0.4793	0.6124	0.6930	0.7474	0.8171	0.8609	0.8922	0.9168	0.9380	0.9590
40′	0.1871	0.4602	0.5980	0.6816	0.7380	0.8102	0.8557	0.8881	0.9136	0.9356	0.9573
50′	0.1580	0.4410	0.5836	0.6701	0.7285	0.8034	0.8504	0.8841	0.9104	0.9332	0.9557
5°	0.1289	0.4218	0.5692	0.6587	0.7191	0.7965	0.8452	0.8800	0.9072	0.9308	0.9540
10′	0.0998	0.4026	0.5548	0.6472	0.7096	0.7896	0.8399	0.8759	0.9040	0.9284	0.9524
20′	0.0707	0.3834	0.5404	0.6358	0.7002	0.7828	0.8347	0.8718	0.9008	0.9260	0.9507

TABLE II

CORRECTION FACTORS FOR PHASE ANGLE $\left(\frac{\cos\theta}{\cos\theta_2}\right)$

Use With Lagging Load With $(\alpha+\beta+\gamma)$ Negative
Use With Leading Load With $(\alpha+\beta+\gamma)$ Positive

$\alpha+\beta+\gamma$	APPARENT POWER-FACTOR $\cos\theta_2$ 0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90
5′	1.0145	1.0096	1.0071	1.0057	1.0046	1.0033	1.0025	1.0020	1.0015	1.0011	1.0007
10′	1.0289	1.0192	1.0142	1.0113	1.0092	1.0066	1.0050	1.0039	1.0029	1.0022	1.0014
15′	1.0434	1.0288	1.0213	1.0170	1.0138	1.0099	1.0075	1.0059	1.0044	1.0033	1.0021
20′	1.0578	1.0383	1.0284	1.0225	1.0185	1.0133	1.0100	1.0077	1.0059	1.0043	1.0028
25′	1.0723	1.0479	1.0355	1.0282	1.0231	1.0166	1.0125	1.0097	1.0074	1.0054	1.0035
30′	1.0867	1.0575	1.0426	1.0338	1.0277	1.0199	1.0150	1.0116	1.0088	1.0065	1.0041
40′	1.1156	1.0766	1.0568	1.0450	1.0369	1.0265	1.0200	1.0154	1.0117	1.0086	1.0055
50′	1.1445	1.0958	1.0711	1.0563	1.0462	1.0332	1.0250	1.0193	1.0147	1.0108	1.0069
1°	1.1734	1.1150	1.0853	1.0675	1.0554	1.0398	1.0300	1.0231	1.0176	1.0129	1.0083
10′	1.2023	1.1342	1.0995	1.0787	1.0646	1.0464	1.0350	1.0269	1.0205	1.0150	1.0096
20′	1.2311	1.1533	1.1136	1.0899	1.0737	1.0530	1.0399	1.0307	1.0234	1.0171	1.0110
30′	1.2600	1.1725	1.1278	1.1010	1.0829	1.0595	1.0449	1.0345	1.0262	1.0192	1.0123
40′	1.2888	1.1916	1.1419	1.1122	1.0920	1.0661	1.0498	1.0383	1.0291	1.0213	1.0136
50′	1.3177	1.2108	1.1561	1.1234	1.1012	1.0727	1.0548	1.0421	1.0320	1.0235	1.0150
2°	1.3466	1.2300	1.1703	1.1346	1.1104	1.0793	1.0598	1.0459	1.0349	1.0256	1.0163
10′	1.3754	1.2492	1.1844	1.1462	1.1195	1.0858	1.0647	1.0497	1.0377	1.0277	1.0176
20′	1.4042	1.2683	1.1985	1.1578	1.1286	1.0924	1.0696	1.0531	1.0406	1.0297	1.0189
30′	1.4329	1.2875	1.2126	1.1693	1.1377	1.0989	1.0745	1.0572	1.0435	1.0318	1.0201
40′	1.4617	1.3066	1.2267	1.1809	1.1468	1.1054	1.0794	1.0609	[illegible]	[illegible]	[illegible]
50′	1.4905	1.3258	1.2409	1.1925	1.1560	1.1120	1.0844	1.0647	1.0492	[illegible]	1.0227
3°	1.5193	1.3449	1.2550	1.2041	1.1651	1.1185	1.0893	1.0684	1.0520	[illegible]	[illegible]
10′	1.5480	1.3637	1.2690	1.2147	1.1742	1.1250	[illegible]	1.0721	[illegible]	[illegible]	[illegible]
20′	1.5769	1.3824	1.2831	1.2253	1.1832	1.1315	[illegible]	1.0758	[illegible]	[illegible]	[illegible]
30′	1.6056	1.4012	1.2971	1.2359	[illegible]	1.1379	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40′	1.6344	1.4199	1.3111	1.2465	[illegible]	1.1444	1.1087	[illegible]	[illegible]	[illegible]	[illegible]
50′	1.6632	1.4387	1.3252	1.2572	1.2101	1.1509	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4°	1.6920	1.4575	1.3392	1.2678	1.2194	1.1574	1.1184	[illegible]	[illegible]	[illegible]	[illegible]
10′	1.7206	1.4764	1.3532	1.2788	1.2284	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20′	1.7491	1.4952	1.3672	1.2898	1.2374	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30′	1.7777	1.5141	1.3811	1.3007	1.2463	[illegible]	[illegible]	1.1015	[illegible]	[illegible]	[illegible]
40′	1.8062	1.5329	1.3951	1.3117	1.2553	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50′	1.8348	1.5518	1.4091	1.3227	1.2643	1.1896	1.1423	1.1088	[illegible]	[illegible]	[illegible]
5°	1.8634	1.5707	1.4231	1.3337	1.2733	1.1960	[illegible]	1.1124	1.0851	[illegible]	1.0384
10′	1.8920	1.5896	1.4371	1.3447	1.2823	1.2024	1.1520	[illegible]	1.0878	[illegible]	1.0396
20′	1.9205	1.6084	1.4511	1.3557	1.2913	1.2089	1.1568	1.1196	[illegible]	[illegible]	1.0408

tester and careful observance of precautions mentioned later are essential.

The time required for test by this method is long compared with any direct reading method, such as is commonly used in laboratory work, because of the slow running of the meter at the lower current points. A complete ratio and phase-angle test on a current transformer at six current points, using one secondary burden and one frequency, requires about five hours of actual meter running time. This is based on the use of induction test meters having a K of 0.6. The total time for the test will depend on the facilities for regulation, but will generally not be less than seven hours for average conditions. The time may be shortened with satisfactory accuracy in some cases by certain modifications in the apparatus and procedure.

This method has neither the accuracy nor the speed of the null methods commonly used in standardizing laboratories. However, it requires but little specialized apparatus to cover a range of secondary currents between 1.0 and 4.5 amperes, most of the necessary meters and instruments being available at any place where meter calibration is regularly done. All devices needed are portable, and the connections are simple enough to require very little time for assembling in preparation for testing. The field for which the method is adapted is, therefore, the testing of small numbers of transformers where installed, when removal for laboratory test is difficult, yet where the actual characteristics must be determined within fairly close limits. It is not satisfactory either for rough checks of transformer condition or for high-grade laboratory work.

Apparatus

The following standard apparatus is required to secure the grade of accuracy mentioned, at secondary currents from 1.0 to 4.5 amperes with a 110-volt supply (the addition of a voltage multiplier for the wattmeter will extend the current range to include 5 amperes):

- One 150-volt voltmeter
- One 5-ampere ammeter
- One 5-ampere, 150-volt wattmeter
- Two 10-ampere, 110-volt induction test meters ($K = 0.6$)
- One or more standard current transformers to give the same ratios as those under test.
- One set of switches and leads similar to that shown in Fig. 1
- One 110-volt portable phase shifter
- One resistance box for demagnetizing.

One set of the following additional instruments, (*a*) or (*b*), is required in order to extend the current range to include 0.5 ampere:

(*a*) Special Instruments:
- One 2.5-ampere ammeter
- One 2.5-ampere, 150-volt wattmeter

(*b*) Standard Instruments:
- One 2.0-ampere ammeter
- One 4.5-ampere, 125/250-volt wattmeter

The apparatus is shown in Fig. 1.

Portable current transformers having several ratios may be used as standards. An additional transformer of the same rating may be used to step up the current where necessary.

The induction test meters must be designed for the frequency of the circuit on which tests are to be made. Meters having 5-ampere coils may be used in some cases.

The special instruments (*a*) are designed to have an impedance equal to that of standard instruments having twice the range. These instruments are not ordinarily available.

The standard low reading instruments (*b*) may be used if a special calibration of the standard current transformer is made with the low reading instruments connected in.

An ordinary phase shifter will not give as good accuracy as the one listed.

Referring to Fig. 2 it should be noted that switches *1* and *2* are rated 250 volts and 100 amperes. Switch *1* has heavy leads soldered across and shunting the central sliding contacts.

Heavy leads (100/25 dynamo cable) are used for all parts of the secondary testing circuit.

The minimum secondary burden for the transformer under test including test meter, switch, and about 15 feet of leads (secondary testing circuit) has an impedance of about 0.03 ohms (0.75 volt-amperes at 5 amperes 60 cycles).

Precautions

The following precautions must be taken to secure accurate results:

The current transformers used as standards must be carefully calibrated with the secondary burden to be used, as all results are based on the constants of the standards.

In order to obtain an accuracy within 0.2 per cent in ratio and 10 minutes in phase angle, the standard transformer and transformer under test should not differ more than 5 per cent in ratio and 1 degree in phase angle at any point.

The two induction test meters or watthour meters must not differ more than 2 per cent in rates at any point at unity power-factor or at 0.5 power-factor. They should be properly lagged and the difference in rates at 0.5 power-factor should be in the same direction as at unity. The meters should not creep.

A phase-shifting transformer of good quality should always be used to obtain exact unity power-factor. At 110 volts, the variation in voltage at different rotor positions should not exceed 1.5 volts.

Care should be taken to make "equivalent" secondary burdens for the transformer under test exactly equivalent to the burdens they are intended to represent.

All transformers should be demagnetized before being tested.

The secondary circuits should not be opened with primary current flowing.

Good contacts must be obtained in making all connections in the secondary circuits; the contacts of the switches in the secondary circuits must be kept clean. Good contacts must also be maintained in the potential circuit of the watthour meters.

All readings must be carefully taken. The test meter dials should be read to 0.1 division, and readings should be made quickly to avoid errors due to the slight creeping which may occur even in a properly adjusted meter due to vibration. The indicating wattmeters should give maximum deflection exactly at given voltage and current, without regard to calibration, in ratio tests. In phase-angle tests, the scale should be read to 0.1 division.

A sufficient number of revolutions of the meters must be taken at each point.

Testing Circuit

Fig. 2 shows a schematic diagram of the apparatus and connections.

The primary windings of the standard current transformer and of the transformer under test are connected in series with a suitable source of current. One watthour meter (and other devices if desired) is connected in each secondary circuit. One secondary lead is common to both transformers. The watthour meters (*A* and *B*) are interchanged by means of switch *1*. Switch *3* is closed when switch *1* is open to prevent opening the secondary circuits. Switch *4* is in the potential circuit of the watthour meters and is used to start and stop them. Switch *2* is used to short circuit the current coils of one set of indicating instruments. It should be noted that the current coils of the indicating instruments are all connected in the secondary circuit of the standard transformer. An indicating voltmeter is also used. The phase-shifting transformer is used to obtain exact unity power-factor for the ratio test and 0.5 power-factor lagging for the phase-angle test.

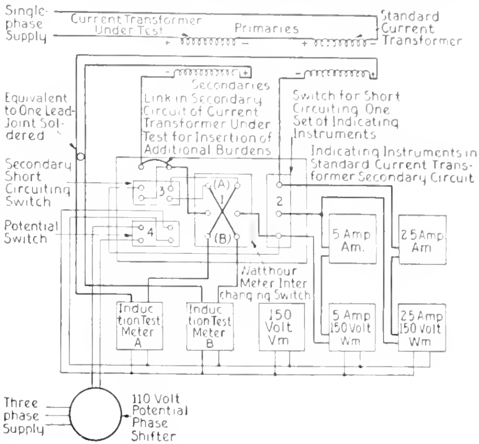


Fig. 2. Diagram of Connections for Ratio and Phase-angle Tests of Current Transformers by Watthour Meter Method

PROCEDURE

The following procedure has proved satisfactory:

(*a*) **Testing**

With connections and apparatus as shown in Fig. 2:

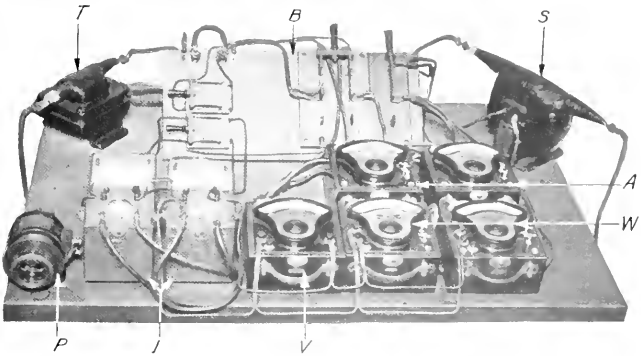


Fig. 1. Apparatus for Testing Current Transformers by the Watthour Meter Method

S. Standard Current Transformer
T. Transformer Under Test
I. Induction Test Meters
V. Voltmeter
A. Ammeters
W. Wattmeters'
P. Phase Shifter
B. Switchboard

Throw switch *1* up (position *A*) connecting meter *A* in the standard transformer secondary circuit and meter *B* in the secondary circuit of the transformer under test.

Switch *2* should be closed one way (say up) short circuiting the low reading ammeter and wattmeter.

Close switch *4*, applying potential of desired value (say 110 volts) to the induction test meters and to the indicating instruments.

Switch *3* (which in effect throws switch *1* up, thus keeping the secondary circuits closed when switch *1* is reversed) should be open.

Current should then be applied to the primaries of the two current transformers.

Adjust the primary current until the secondary current of the standard current transformer has the desired value (say 3.0 amperes) as shown by the 5-ampere ammeter.

Rotate the phase shifter until an exact maximum deflection is obtained on the wattmeter with constant voltage and current. This should be done with meters *A* and *B* running.

Hold the correct number of revolutions (say 20) as tabulated under revolutions on meter *A* (this is reading a_1) and read meter *B* (reading b_2).

Close switch *3* and throw transfer switch *1* down (position *B*) connecting meter *B* in the standard transformer secondary circuit and meter *A* in the secondary circuit of the transformer under test.

Open switch *3*.

Hold the same number of revolutions (20) on meter *B* (reading b_1) and read meter *A* (reading a_2). b_1 should equal a_1.

The readings of the indicating instruments should be checked occasionally.

Repeat until the stated number of revolutions (120) at one point have been taken, tabulating the results as indicated in Table III.

Reduce the power-factor to 0.5 lagging by rotating the phase shifter, obtaining A_1, B_2 and B_1, A_2 respectively (corresponding to a_1, b_2 and b_1, a_2). B_1 should equal A_1. The total number of revolutions should be the same (120) as in the ratio test. The condition of lagging power-factor is shown by the reversal of the reading of the indicating wattmeter when a condenser of about one micro-farad capacity is placed in series with the potential circuit.

The same procedure should be repeated for each point.

Meters *A* and *B* should be started and stopped by closing and opening switch *4*.

TABLE III

RATIO TEST AT UNITY POWER FACTOR

(Form suggested for tabulating results, showing minimum number of revolutions required at each point)

Secondary Amperes	STANDARD TRANSFORMER			TRANSFORMER UNDER TEST*	
	Revolutions				
	a_1	b_1		a_2	b_2
0.5	5				5 ±
		5		5 ±	
	5				5 ±
		5		5 ±	
	5				5 ±
		5		5 ±	
	5				5 ±
		5		5 ±	
	20	20	Totals	20 ±	20 ±
1.0	10				10 ±
		10		10 ±	
	10				10 ±
		10		10 ±	
	10				10 ±
		10		10 ±	
	30	30	Totals	30 ±	30 ±
2.0	15				15 ±
		15		15 ±	
	15				15 ±
		15		15 ±	
	15				15 ±
		15		15 ±	
	45	45	Totals	45 ±	45 ±
3.0	20				20 ±
		20		20 ±	
	20				20 ±
		20		20 ±	
	20				20 ±
		20		20 ±	
	60	60	Totals	60 ±	60 ±
4.0	25				25 ±
		25		25 ±	
	25				25 ±
		25		25 ±	
	25				25 ±
		25		25 ±	
	75	75	Totals	75 ±	75 ±
5.0	30				30 ±
		30		30 ±	
	30				30 ±
		30		30 ±	
	30				30 ±
		30		30 ±	
	90	90	Totals	90 ±	90 ±

* The plus or minus (±) signs indicate that the values are approximate.

If the special low reading ammeter and wattmeter are not available and standard low reading instruments are substituted at 0.5-ampere, a different set of standard transformer constants, which were obtained with this special secondary burden, must be used.

The numbers of revolutions and runs in Table III should be taken for both ratio and phase-angle tests. The correct number of revolutions should be held on meter A (reading a_1) for the first run and on meter B (reading b_1) for the second run, so that $a_1=b_1$ if possible. This reduces to a minimum the error caused by a difference in the rates of the two watthour meters.

A series of short runs, interchanging the two meters at each step, is preferable to a smaller number of longer runs. This minimizes any error caused by a change in the meter rates. The total number of revolutions tabulated at each current point in Table III are the minima which will give the accuracy that has been defined.

The ratio tests should be made at exact unity power-factor.

A similar set of readings is taken for the phase-angle tests. The column headings for the different meter revolutions are A_1, B_1, and A_2, B_2 respectively, instead of a_1, b_1 and a_2, b_2 respectively, which are used for the ratio tests.

The phase-angle tests should be made at 0.5 power-factor lagging.

Both ratio and phase-angle tests at each point should be completed before checking the next point.

(b) Formulas

The following formulas should be used:

Let R_1 = Ratio of standard current transformer.

R_2 = Ratio of current transformer under test.

β_1 = Phase angle of standard current transformer.

β_2 = Phase angle of current transformer under test.

a_1, b_1 = Revolutions of watthour meters A and B respectively at unity power-factor in ratio test, when supplied from the secondary of the standard transformer.

a_2, b_2 = The same for the secondary of the transformer under test.

A_1, B_1, A_2, B_2 = Same as above except taken at low power-factor for phase-angle test.

Cos θ_2 = Power-factor on watthour meter supplied from secondary of standard transformer.

Cos θ = Power-factor on watthour meter supplied from secondary of transformer under test.

δ = Phase angle between the secondary currents of the two transformers.

$\delta = \beta_1 - \beta_2$.

θ_o = Angle between the voltage applied to the watthour meters and the primary current for ratio test; this angle is approximately zero.

θ_1 = Angle between the voltage applied to the watthour meters and the primary current for phase-angle test; this angle is approximately 60 deg.

For the ratio test

$$R_2 = R_1 \times \frac{a_1+b_1}{a_2+b_2} \qquad (1)$$

For the phase-angle test

$$\frac{\cos\theta}{\cos\theta_2} = \frac{A_2+B_2}{A_1+B_1} \times \frac{a_1+b_1}{a_2+b_2} \qquad (2)$$

In Tables I and II let $\alpha+\beta+\gamma$ (the left-hand column) represent δ.

Find the value of $\frac{\cos\theta}{\cos\theta_2}$ obtained in formula (2) under the value of cos θ_2 (power-factor) used in the phase-angle test.

On the same line at the left in column headed $\alpha+\beta+\gamma$ is found the desired value of δ: then

$$\beta_2 = \beta_1 - \delta \qquad (3)$$

If the phase-angle tests have been made at lagging power-factor, the sign of δ is negative (−) for all values of $\frac{\cos\theta}{\cos\theta_2}$ over unity and positive (+) for all values below unity; this is reversed if tests have been made at leading power-factor.

Particular regard must be paid to the respective signs in formula (3).

For exceptional cases where it is not possible to obtain unity power-factor in the ratio tests, formula (1) must be multiplied by $\frac{\cos(\theta_o \pm \beta_2)}{\cos(\theta_o \pm \beta_1)}$ where this factor differs as much as 0.1 per cent from unity value.

When the ratios of the standard transformer and the transformer under test differ by more than 5 per cent, formulas (1) and (2) should be rechecked by the following formulas:

$$R_2 = R_1 \sqrt{\frac{a_1 b_1}{a_2 b_2}} \qquad (4)$$

$$\frac{\cos\theta}{\cos\theta_2} = \sqrt{\frac{A_2 B_2}{A_1 B_1}} \times \sqrt{\frac{a_1 b_1}{a_2 b_2}} \qquad (5)$$

These formulas should be used for calculation if the result differs from that obtained by formulas (1) and (2) be more than 0.05 per cent in ratio, or 3 minutes in phase angle.

Where the ratios differ by 25 per cent or more, errors occur due to difference in meter rates at different current points. These errors are not eliminated by using the more accurate formulas and the accuracy of the result may be outside of the estimated limit of 0.2 per cent in ratio and 10 minutes in phase angle.

(c) Calculations

The following rules should be used in making calculations:

When both the standard transformer and the transformer under test have the same marked ratio, and when the ratio results are desired in terms of the transformer accuracy, the $\frac{\textit{true ratio}}{\textit{marked ratio}}$ of the standard transformer should be used instead of R_1 in formula (1).

Use of Slide Rule

While the slide rule is not sufficiently accurate to obtain ratios directly, it may be used by well-known subtractive methods with considerable saving of time in calculations and without decrease of accuracy. For instance, the value of $\frac{a_1+b_1}{a_2+b_2}$ in formula (1) is nearly unity. Direct application of the slide rule gives an accuracy of about 0.1 per cent, which is not sufficient. By the following process, satisfactory accuracy may be obtained.

Let Y equal the difference between a_1+b_1 and a_2+b_2

When $a_1+b_1>a_2+b_2$

$a_2+b_2+Y=a_1+b_1$ and

$$\frac{a_1+b_1}{a_2+b_2}=\frac{a_2+b_2}{a_2+b_2}+\frac{Y}{a_2+b_2}=1+\frac{Y}{a_2+b_2}$$

The last division should be performed with a slide rule. For example, let

$$\frac{a_1+b_1}{a_2+b_2}=\frac{20+20}{19.88+19.9}=\frac{40}{39.78}$$

The difference is 0.22, so

$$\frac{a_1+b_1}{a_2+b_2}=\frac{40}{39.78}=1+\frac{0.22}{39.78}$$

$$=1+0.0055 \text{ or } =1.0055$$

Similarly, when $a_1+b_1<a_2+b_2$

$a_2+b_2-Y=a_1+b_1$ and

$$\frac{a_1+b_1}{a_2+b_2}=\frac{a_2+b_2}{a_2+b_2}-\frac{Y}{a_2+b_2}=1-\frac{Y}{a_2+b_2}$$

For example, let

$$\frac{a_1+b_1}{a_2+b_2}=\frac{20+20}{20.12+20.1}=\frac{40}{40.22}$$

TABLE IV

READINGS OBTAINED IN TEST ON A 2:1 RATIO CURRENT TRANSFORMER

Ratio Test

INSTRUMENT READINGS				REVOLUTIONS			
				Standard Transformer		Transformer Under Test	
Volts	Amp.	Watts	P-F.	a_1	b_1	a_2	b_2
110	2.0	220	1.0	15.009			14.945
					15.005	14.98	
				15.006			14.942
					15.002	14.983	
				14.99			14.924
					15.012	15.00	
			Totals	45.005	45.019	44.963	44.811

Phase Angle Test

Volts	Amp.	Watts	lag.	A_1	B_1	A_2	B_2
110	2.0	110	0.5	15.005			15.001
					15.005	15.046	
				14.999			14.98
					15.000	15.026	
				15.00			14.976
					15.002	15.029	
			Totals	45.004	45.007	45.101	44.957

The difference $Y = 0.22$, so

$$\frac{a_1+b_1}{a_2+b_2} = \frac{40}{40.22} = 1 - \frac{0.22}{40.22}$$
$$= 1 - 0.0055 \text{ or } = 0.9945$$

Similarly, when multiplying two quantities which are each nearly equal to unity, as in formula (2), make the following change and use the slide rule.

Separate one of the quantities into two parts, one of which is unity. For example, $1.0055 = 1 + 0.0055$, or $0.9945 = 1 - 0.0055$

Multiply the other quantity by these two parts separately using the slide rule for the one operation.

For example, let

$$\frac{A_2+B_2}{A_1+B_1} \times \frac{a_1+b_1}{a_2+b_2} = 1.0055 \times 0.9945$$

Then $1.0055 = 1 + 0.0055$ and

$$0.9945 \times (1+0.0055) = 0.9945 + (0.9945 \times 0.0055) = 0.9945 + 0.0055 = 1.000$$

Also $0.9945 = 1 - 0.0055$ and

$$1.0055 \times (1-0.0055) = 1.0055 - (1.0055 \times 0.0055) = 1.0055 - 0.0055 = 1.000$$

The second multiplication should be made by the slide rule in each case.

Example of Application of Method

The readings given in Table IV were taken in test on a 2:1 ratio current transformer, using another 2:1 ratio current transformer as a standard.

The $\frac{\textit{true ratio}}{\textit{marked ratio}}$ of the standard transformer at this point was 0.9949 ($R_1 = 1.9898$) and the phase angle was +11 minutes as determined by the shunt method.

For the ratio results

$$R_2 = R_1 \times \frac{a_1+b_1}{a_2+b_2} \qquad (1)$$

or

$$\frac{TR_2}{MR} = \frac{TR_1}{MR} \times \frac{a_1+b_1}{a_2+b_2}$$
$$= 0.9949 \times \frac{90.024}{89.774}$$
$$= 0.9949 \times \frac{(1+0.250)}{89.774}$$
$$= 0.9949 \times (1+0.0028)$$
$$= 0.9949 + 0.0028$$
$$= 0.9977$$
$$R_2 = 0.9977 \times 2 = 1.9954$$

For the phase-angle results

$$\frac{\cos\theta}{\cos\theta_2} = \frac{A_2+B_2}{A_1+B_1} \times \frac{a_1+b_1}{a_2+b_2} \qquad (2)$$
$$= \frac{90.058}{90.011} \times \frac{90.024}{89.774}$$
$$= \frac{(1+0.047)}{90.011} \times 1.0028$$
$$= (1+0.0005) \times 1.0028$$
$$= 1.0028 + 0.0005$$
$$= 1.0033$$

Referring to Table II, 1.0033 is found to be between 1.0025 and 1.005 in the column headed 0.5 power-factor ($\cos\theta_2$). The value

TABLE V

RESULTS OF TESTS ON A 2:1 RATIO CURRENT TRANSFORMER

Burden No. 1

Per Cent Primary Current	Shunt Method: True Ratio / Marked Ratio	Shunt Method: Phase Angle	Watthour Meter Method: True Ratio / Marked Ratio	Watthour Meter Method: Phase Angle
10	1.0017	+29′	1.001	+34′
20	0.9997	+21′	0.9996	+23′
40	0.9977	+14′	0.9977	+18′
60	0.9971	+12′	0.9969	+13′
80	0.9967	+10′		
100	0.9959	+ 9′	0.9961	+12′
		Burden No. 4		
10	1.0137	+14′	1.0126	+15′
20	1.0077	+ 9′	1.0076	+10′
40	1.003	+ 4′	1.0028	+ 5′
60	1.0009	+ 4′	1.0012	+ 5′
80	0.9997	+ 4′		
100	0.9991	+ 3′	0.9996	+ 5′

[illegible] at the left (column headed $\alpha+\beta+\gamma$) corresponding to 1.0033 is evidently about 7 minutes. The directions for using the table (at the top) state that δ (or $\alpha+\beta+\gamma$) is negative in this case, since the test was made at lagging power-factor.

The desired phase angle is

$$\begin{aligned} \beta_2 &= \beta_1 - \delta \\ &= +11' - (-7') \\ &= +18' \end{aligned} \quad (3)$$

The complete data taken on this transformer is given in Table V.

Time Required

The time required for a complete ratio and phase-angle test (six current points) at one secondary burden and one frequency will depend on the facilities for regulation; the actual meter running time is about five hours. The time required for regulating the current and power-factor at each point and for interchanging the meters must be added to the running time of the meters. The running time for a three-point check is two and a half hours.

This estimate of running time is based on the use of induction test meters with a constant of 0.6 for the 10-ampere coil. The 10-ampere coils are used on account of their low impedance which, when combined with that of the necessary secondary leads and switches, makes a secondary burden about equal to that of a switchboard watthour meter. This permits the complete secondary testing circuit to be substituted for the current coil of a switchboard watthour meter and thus the current transformer tested with practically its exact normal secondary burden.

If special secondary burdens for use in testing are to be made up, it is usually possible to use induction test meters with 5-ampere current coils and thus cut the meter running time in half and also secure better accuracy at the lower current points.

The use of meters with one-ampere or two-ampere coils to reduce the time of test is usually impracticable because of the large increase in the secondary burden on the transformer tested.

The speed of the meters may also be increased by shunting the drag magnets. This is inconvenient when the meters are also to be used for other testing, as recalibration is desirable after removing the shunt. The meter rates with the shunts must be adjusted each time within 2 per cent of each other. For this purpose, a set screw should be provided for adjustment of the shunt. On the whole, the advantage gained is rather questionable.

Even under the best conditions, however, the time required for testing greatly exceeds that required by the more precise shunt method of calibrating current transformers. In the shunt method, about 15 minutes are required for the complete ratio and phase-angle test (six current points) at one secondary burden and one frequency.

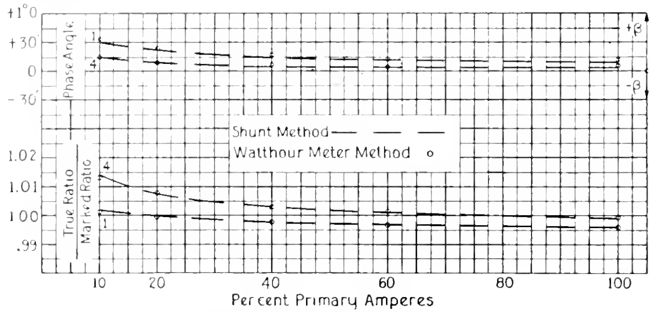


Fig. 3. Comparative Curves of Results Obtained by Watthour Meter Method and by Shunt Method of Testing a 2:1 Current Transformer for Ratio and Phase Angle

Results of Test

The results given in Table V were obtained in testing a 2:1 ratio current transformer of type W_2. The transformer was tested for ratio and phase angle at 60 cycles with two different secondary burdens by both the watthour meter method and the shunt method. For comparison, both sets of results are plotted in Fig. 3.

The $\frac{\textit{true ratio}}{\textit{marked ratio}}$ and phase angle are plotted against per cent primary current instead of secondary amperes.

In these tests, a 2:1 ratio current transformer of Type K was used as a standard.

The maximum difference in either test is 0.09 per cent in ratio and 5 minutes in phase angle.

Burden No. 1 had an effective resistance of 0.396 ohms and an inductance of 510 microhenries (11 volt-amperes at 0.9 power-factor at 5 amperes and 60 cycles).

Burden No. 4 had an effective resistance of 0.97 ohms and an inductance of 4035 microhenries (15 volt-amperes at 0.51 power-factor at 5 amperes and 60 cycles).

Summary

The watthour meter method is applicable to the testing of current transformers in place with satisfactory accuracy but its use should be limited to cases where it is not practicable to send the transformer to a properly equipped laboratory. The method is necessarily slow, because of the time required for an integration of sufficient energy to render minor errors negligible. Careful testing is essential to secure satisfactory accuracy.

The time required is considerably reduced by the improved formulas and methods of calculation presented in this article. Errors inherent in the method are minimized by following the procedure suggested.

Lubrication of Steam Turbines*

I. STATIONARY OUTFITS—BEARINGS

In our May issue we promised our readers a series of articles on the important subject of lubrication, the first of which was published in the same issue and was in the main a discussion of the several methods that are employed for keeping steam turbine lubricating oil in good condition. The present article, which will be published in two parts, reviews the general principles of oil lubrication with special reference to turbine bearings, consideration being given to the effects of speed, clearance, cooling by means of oil circulation, viscosity, and emulsification; and as a conclusion to Part I the specifications of a satisfactory lubricating oil for steam turbines are given. Part II will consider the lubrication of steam turbine reduction gears with special reference to marine outfits. Further description and comments will be made on the methods and means of keeping the lubricating oil in good condition.—EDITOR.

For the purpose of analyzing lubricating requirements, steam turbines may be divided into the following general classes:

1. Horizontal or vertical.
2. Direct drive or reduction gear drive.
3. Stationary or marine.

The majority of steam turbines, especially the smaller units, are of the horizontal direct drive stationary type, though many of the latest large machines drive through gears. This latter construction is specially used in the case of marine outfits, as the speed is determined by the speed of the propeller. We shall study first the lubrication of the horizontal direct drive stationary type, and then consider what changes or further details are required by the other types.

Metallic Friction

Metallic surfaces, no matter how well polished, are microscopically rough. When two such surfaces are rubbed together the small projections and depressions tend to interlock. This can be overcome only by a tearing away of the projections, compressing or pushing them aside, or by the separation of the sliding surfaces sufficiently by a lubricant to allow the projections to pass each other. When the sliding surfaces are thus covered with a lubricant, in order that the projections may interlock the lubricant must be pushed from the depressions and from around the projections. While liquids are mobile and will work out gradually from between two surfaces under pressure, yet the resistance to flow, or viscosity of the liquid, hinders the action and considerable time may elapse before the surfaces come into contact.

When oil is between two surfaces they will not, under ordinary conditions, be forced into as close contact as if the surfaces are dry; even if a long time is allowed for the action to take place. This is due to the property of most liquids to adhere to or to "wet" solids. This action is very strong indeed in the case of oils with metals, and is one of the governing factors which makes them such excellent lubricants. It is very difficult to rub all the

* By the courtesy of The Texas Company.

oil from a metal surface unless heated, as the oil seems to get into the pores of the metal and refuses to be displaced.

This adhesive property of oil, however, although assisting in lubrication, is not sufficient in the case of turbines to maintain a film of oil between the rotating journal and the bearing, and prevent metallic contact. The maintenance of a film will depend primarily on the character of surface, load per square inch, rubbing speed, clearance, and viscosity of the oil at the temperature of the bearing. Smooth surfaces can operate with less clearance than rough ones, and hence will require less thickness of oil film to keep them out of contact. An increase in load on a bearing naturally tends to force the oil out and the parts nearer together, and, other things being equal, when a bearing is subjected to a heavy load, a higher viscosity oil is necessary to keep the parts out of contact than when the load is light.

Effect of Speed

The rubbing speed affects the amount of oil dragged into, or out of, a bearing. As previously stated, a film of oil adheres tenaciously to the revolving journal, and on account of the viscosity of the oil the adjacent layers to that adhering to the metal are dragged with it. These are resisted from entering the clearance space by the fact that the oil already there is being forced out by the weight of the bearing. This latter force is practically a constant, while the force dragging the oil with the journal is proportional both to rubbing speed and viscosity of the oil. It is thus seen that at high rubbing speeds an oil of less viscosity is required in order to maintain an oil film against the expulsion force than at low speeds.

Clearance Space

The design of the bearing greatly influences the maintenance of an oil film. As mentioned above, a revolving journal drags the oil into the clearance space. This is assisted by having this clearance space somewhat larger at the point of entrance of the oil than at the other parts of the bearings. This forms a wedge of oil, the oil entering at the thick part of the wedge and going out at the thin edges. Analysis has shown that the pressure in the oil film varies in different parts, the least pressure existing at the top and sides of the bearing. It is therefore necessary that the oil be introduced at these points of low pressure. The clearance space allowed in most turbine bearings is 1/1000 inch for each one inch diameter of journal. In modern high speed bearings using light oils it has been found that no oil grooves should be used, as they may allow the loss of the built up oil pressure in the bearings space. In some bearings, however, oil grooves are still used.

Fluid Friction

We have discussed the elimination of metallic friction by the interposition of an oil film. This does not entirely do away with friction, as the oil itself presents a resistance which may become quite considerable. As we have previously seen, oil adheres quite tenaciously to metal surfaces. Therefore, in sliding one surface over another separated by an oil film, the sliding takes place in the oil body and not between the oil and metal. The viscosity of the oil resists this shift in the oil film or, practically speaking, the sliding of two oil films over each other, and energy must be expended to bring it about. The amount of energy required to turn a journal in a bearing, if the clearances do not change, is proportional to the viscosity of the oil and the speed of rotation. It can readily be seen, therefore, that while at low speed the heat generated may be small, at the high speed necessary in turbines the heat due to friction may be very great. This is accentuated by the fact that for many reasons it is desirable to have small clearance spaces, and, by the nature of viscosity, the friction resistance in the oil body is inversely proportional to the thickness of the film. This frictional heat therefore increases with decreasing thickness of film.

Cooling Effect of Oil

This heat is generated so rapidly that it is impossible for it to be radiated or conducted away as quickly as produced, and it is one of the principal functions of the oil to carry away this heat. This is very essential, as the viscosity, and hence supporting power, of the oil drops rapidly with temperature rise, and may quickly reach a point where the oil ceases to keep the metal surfaces apart and there will be seizing. It is customary, therefore, to use a large quantity of oil, forcing it into the bearing under pressure. Part of the oil passes through the clearance space while the excess acts as a cooling agent before draining back into the sump tank. The top of the bearing brasses may be slotted to allow the oil to get at the journal and keep it cool. The bottom brass is not so easily cooled, as only oil in the clearance space comes in contact with it, and this oil is very hot. The cooling here is practically all by conduction to some surface over which the main body of oil is flowing, unless the oil is forced through the clearance space.

The temperature of the oil into and out of a bearing will vary according to the amount of oil being flooded through it, but often shows a rise of 15 deg. to 20 deg. F. When it is considered that this heat, which is distributed in a large volume of oil, is in most cases produced in only that small portion passing through the clearance space, it is evident that the temperature of the oil film may be exceedingly high, and only the best grade of oil will withstand it.

To this heat must be added the heat conducted along the shaft and housing from the turbine. Some bearings may be water cooled to cut this down, but in most cases the oil is required to carry off this heat. Oil temperatures of 175 deg.–185 deg. F. are not unusual. This high general temperature, however, need not necessarily cause any alarm provided the rise in the oil film is not excessive. The matter of temperature depends on the design of bearing and viscosity and volume of the oil. As previously stated, oils decrease rapidly in viscosity as the temperature rises, and the value of an oil as a lubricant will depend on the viscosity at the working temperature and not on its rated viscosity, usually taken at 100 deg. F. In fact, if the oil is also required to work on gears, it may be necessary to heat it so that its viscosity is sufficiently reduced to operate satisfactorily in the bearings.

Viscosity

There are a number of formulas purporting to give the viscosity of an oil required to operate in a turbine bearing of stated dimensions. Some of these may give a general idea, but it is unsafe to depend too much upon them without making some experiments on the actual piece of apparatus under consideration. While in many cases an oil having a viscosity of about 150 sec. Saybolt at 100 deg. F. may operate satisfactorily, slight variations in bearing clearances or alignment, and different speeds and temperatures may entirely alter the requirements. It is axiomatic, however, that it is better to have an oil of too high viscosity than one of too low a value. The more viscous oil will cause higher fluid friction and consequently a higher bearing temperature, but this condition will soon be partially corrected as the viscosity will go down with rising temperature, reducing the friction until a working equilibrium is reached, and the temperature will not rise further. On the other hand, if the viscosity is too low there may be metallic rubbing with a rise in temperature which, further reducing the viscosity, will decrease the bearing power of the oil and seizing will soon result. This is an unstable condition which is very undesirable and apt to be overlooked when too much attention is paid to getting the oil with the lowest viscosity that will work under the normal operating temperatures.

There are a number of other factors besides viscosity which influence the choice of an oil for a turbine bearing, and these will now be considered.

Evaporation

The turbine oiling system is usually a tightly enclosed affair, as free from oil leaks as it is possible for mechanics to make, consequently there is very little loss of oil and the initial charge lasts a long time. Any petroleum oil when agitated in the presence of air at the temperatures of the bearing will vaporize to a certain extent, depending on the characteristics of the oil. Some of the lighter portions of the oil will be driven off, no matter how tightly the system may be enclosed, and the remainder of the oil will slowly thicken and increase its viscosity. Properly refined oils having a minimum evaporation will last a long time without any serious increase in viscosity due to this cause, and there are records of turbines operating for years on one charge of oil, only a small amount being added from time to time to make up for evaporation and leakage. The leaving of a single charge of oil in a turbine for a long time without some sort of attention is not to be recommended, however.

Decomposition

Perhaps the greatest effect of the high bearing film temperature on an oil is a slow decomposition and possible oxidation. All petroleum oils, when subjected to high temperatures, slowly change their composition, and if air is present there may be a slight oxidation. This results in an admixture of undesirable compounds that may cause gumming, emulsification, and under extreme conditions, and specially if water is present, there may be a slight corrosion. This latter effect is, however, largely overdrawn and almost all cases of supposed corrosion can be traced to other causes. The petroleum acids which may be found in small quantities are quite inactive, and even in the presence of water must be quite concentrated to have any corrosive effect.

This slow breaking down usually manifests itself by a darkening of the oils, which, however, may proceed for a long time before the lubricating qualities of the oil will be seriously affected. The pale oils on account of their light color show this darkening more rapidly than dark oils, but are in reality not decomposed any more than, if as much as, the red oils.

Emulsification

The most important effect of the gradual breaking down of oils is the formation of oil bodies which emulsify with water. Highly refined oils of proper character when shaken with water will separate from the water very quickly if allowed to stand quietly a few seconds. Water, in practice, cannot be kept out of the turbine oiling system. It may come from leaks in the bearing cooling water jackets or in the oil cooler pipes, from steam leaking through the stuffing boxes, from moist air drawn into the system, from cooling or steam heating coils in the filtering system, etc. If the oiling system has been properly designed and is of ample capacity, when a suitable oil is used all of the entrained water will separate from the oil in the reservoir and may be drained off, but if the amount of oil in the system is too small, requiring rapid circulation, there is not enough time for the water to separate and it is carried with the oil to the bearings. The quality of two oils being the same, the oil with the lower viscosity and the lower specific gravity will separate from water the more readily.

When oils are used which are not properly refined and filtered for this purpose, the continued agitation of the oil and entrained water will form an emulsion. The oil becomes thickened and picks up and holds foreign particles getting into the system, which act as abrasives when the oil is supplied to the bearings. As the oil becomes thicker and thicker, it finally reaches a point where it will not flow properly through the oil pipes and bearing grooves, and the bearings, not receiving proper lubrication, become hot and wear.

Naturally the best means of preventing emulsion is not to allow water or steam into the system. As this is practically impossible, a place must be arranged in the filtering system where the oil can come to comparative rest, and the water allowed to settle out. It may be advisable to heat the oil so as to allow this settling to take place more rapidly. If the amount of oil used in a system is large and the emulsion small, it is not necessary to treat the whole quantity of oil each time it passes through the lubricating cycle, but a portion may be continually by-passed, settled and then passed back to the main supply.

Any oil to be suitable for turbine use must have a high resistance to emulsification. This quality depends on the character of the oil and the treatment which it has undergone in refining. Oils suitable for turbine use will separate very quickly from hot water and leave the water only slightly cloudy. Oil can be compared for emulsibility by shaking equal quantities with equal quantities of water and allowing to stand. In this connection, however, it must be remembered that oils with high viscosities separate more slowly than those with low viscosities.

Akin to the emulsifying action of oil in a turbine system is foaming. This manifests itself in an overflowing of the reservoir or at some other open vent. It is caused by the presence of a temporary emulsion which is formed by some agitating action more rapidly than it can settle out. This emulsion may either be a mixture of oil and water or oil and air. It naturally is more prone to form with heavy viscous oils than with the more fluid ones. The remedy is an ample sized drain line, and a settling tank of good proportions, heated if necessary.

Sludge

When some oils break down under heat and pressure there may be formed certain types of petroleum compounds which are more or less insoluble in the oil mass. These compounds usually settle out in the settling tank in the form of a sludge, or are filtered out by the filters; but if there are any pockets in the lubricating lines they are apt to settle there, specially if the settling or filtering units are not efficiently operated. If the oil pumps are always run at the same speed, and no large amounts of new oil are added, this settling of the gummy products will not do much harm provided the whole system is cleaned at stated intervals. But on the other hand, if for any reason the pumps are speeded up or an oil of a different character is added to the system, this gummy sludge may become dislodged or dissolved loose from its resting place and cause no end of trouble in the system. If it is surmised that the sludging is taking place it is better to remove a little oil at a time, using it for other purposes and replacing by fresh oil. Or if the oil seems to be all right otherwise, the batch removed may be returned after cleaning.

Foundations

One of the most essential items in the installation and operation of steam turbines is the foundation on which the unit rests. When it is considered how small are the bearing clearances allowed, it is evident that any sagging or shifting due to strains or improper setting up may so change the alignment as to cause the bearings to bind and run hot. The foundation must be absolutely rigid with smooth surface for attaching the base of the unit. In setting up the machine base, means should be provided for compensating for any unequal metal expansion due to unequal heating. In addition flexible couplings may be provided between the turbine and driven apparatus, but these should be in the nature of an extra precaution and not as an essential detail. The parts of the unit should run in alignment without the coupling. Couplings should be lubricated.

Another feature which must be considered in any oiling system is the oil operated governor. In some types these become quite warm, and the oil should be kept free from gum or emulsions. They usually operate under pressure of oil, the excess draining into the sump tank.

Specifications

In regard to the proper specifications for an oil that will lubricate turbine bearings at a minimum cost of operation, it is difficult to make a definite statement that will hold in all cases. It can be stated, however, that:

1. It should be a highly refined mineral oil without any mixture of fatty oil.

2. It should be straight run and show a low evaporation loss when heated to 175 deg. F.

3. It should resist emulsification with water to as high a degree as is practical to manufacture. There is some difference of opinion as to how a standard emulsification test should be carried out, but a rough idea can be made by shaking equal quantities of oil and water vigorously and watching how quickly they separate. A good oil should separate in a few seconds without any pronounced collar of unseparated emulsion.

4. The flash point should be over 320 deg. or sufficiently high to indicate a low evaporation percentage.

5. Acidity: Less than 0.07 milligram potassium hydroxide should be required to neutralize 1 gram oil.

6. Viscosity: If bearing clearance spaces are uniform in thickness, alignment perfect, and speed high, an oil of 150 sec. Saybolt viscosity will probably operate satisfactorily provided the temperatures do not go over 175 deg. F. But as we have stated previously, alignment and clearance spaces are rarely ever perfect and if metallic contact takes place to any extent due to unusual circumstances, the heating thereby caused will result in the lowering of the viscosity in the rubbing film and seizing will soon follow. We therefore feel safer in recommending an oil of 180–200 sec. viscosity at 100 deg. F., believing that a slight extra heating of a bearing is better than a burned out one. In large turbines it may be necessary to go to higher viscosities but designers usually keep the bearing unit pressures low enough to allow of the 180–200 sec. oil being used.

In a later article we shall consider the lubrication of reduction gears, and discuss purifying and operating systems, particularly as applied to marine outfits.

High Frequency Absorbers

PART II

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Pittsfield Works, General Electric Company

[illegible] art I, which discussed the condenser-resistance type of absorber, was published [illegible] the Review. Part II discusses the inductance-resistance type of absorber. For the [illegible] of comparison, the method of treatment has been made very similar to that of [illegible]

Inductance-resistance

In Part I of this article we discussed high frequency absorbers consisting of a condenser in series with a resistance. We will now consider absorbers consisting of an inductance shunted by a resistance. The theoretical treatment will be similar to that used in connection with the condenser-resistance and is given in Appendix II. The inductance and resistance will be regarded as concentrated.

As in Part I, the action of this device will be investigated in connection with:

a Sustained oscillations.

b Rectangular waves of different lengths.

a Sustained Oscillations

With a given inductance and a high frequency oscillation of given current I_1, the dissipation of energy in the absorber varies with the resistance and with the frequency. Assuming that the oscillation is sustained, the voltage across the absorber is

$$E = RI_R = XI_X$$

where R is the value of the resistance in shunt with the inductance or choke coil. I_R is the current flowing through this resistance. X is the value of the inductive reactance of the choke coil. I_X is the current flowing through the choke coil. The resistance of the choke coil is assumed to be zero.

It is evident that

$$I_R^2 + I_X^2 = I_1^2$$

The energy dissipated in the absorber is

$$RI_R^2 = RI_1^2 \frac{X^2}{R^2 + X^2}$$

This loss is a maximum for $R = X$ as can be proved by the same procedure as used in Part I.

For a given reactance X_1 the maximum loss is

$$RI_R^2 \ (max.) = I_1^2 \frac{X_1}{2}$$

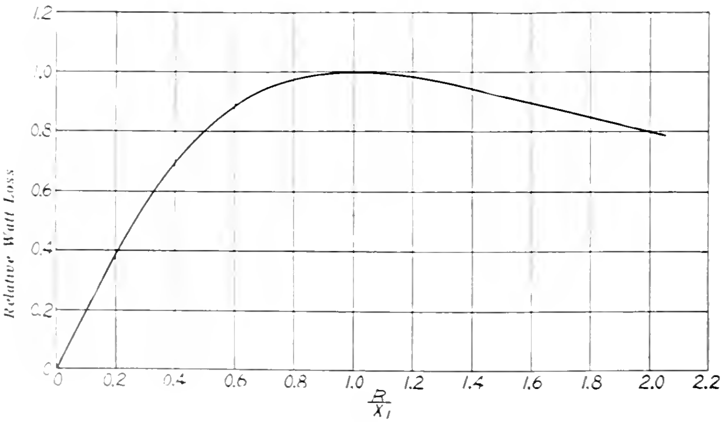


Fig. 12

Let $a=\frac{R}{X_1}$ and substituting in the general equation, we have

$$RI_R^2=I_1^2\frac{X_1}{2}\cdot\frac{2a}{a^2+1}$$

The relative RI_R^2 loss for different values of "a" is shown in Fig. 12, where the maximum loss, namely $I_1^2\frac{X_1}{2}$ is taken as unity. This maximum loss occurs, as we have seen before, at $a=\frac{R}{X_1}=1$. This curve shows, as in the case of the condenser-resistance, that R may be varied over quite a wide range for a given value of X without greatly decreasing the loss.

If L and R are taken as constant, the energy loss varies with the frequency. Let us consider the effect of varying the frequency for several values of R and a given value of L. This variation of the loss with the frequency for different values of R is shown by the curves of Fig. 13, where R is given in terms of X_1, and X_1 is the inductive-reactance at 60 kilocycles. The same ordinates are used as in Fig. 12.

Figs. 12 and 13 show that the resistance may be varied over a considerable range without greatly decreasing the efficiency, and if the absorber is designed to be effective at the lower range of danger frequencies, it will also be effective for the higher range of danger frequencies. 60 kilocycles as pointed out in Part I is approximately the average in the range of the danger frequencies.

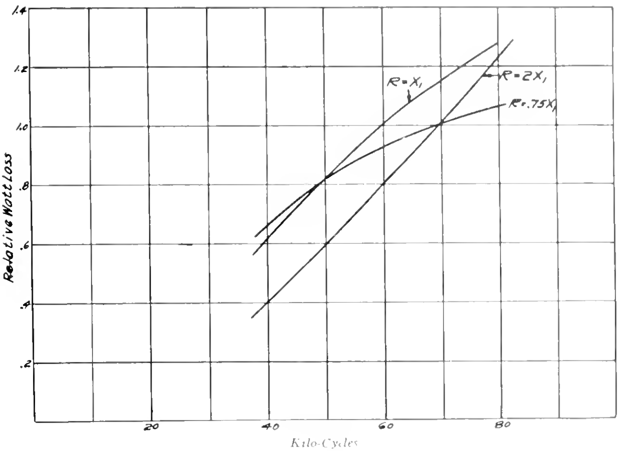


Fig. 13

(b) Rectangular Traveling Waves

The traveling wave will be considered as having a rectangular front passing from circuit *1* of natural impedance Z_1 (see Fig. 11) to circuit *2* of natural impedance Z_2 through a high frequency absorber consisting of a choke coil of concentrated inductance L shunted by a resistor of concentrated resistance R. Part of the energy of the incoming wave is transmitted to circuit *2*, part is dissipated in the resistance R, part is temporarily stored in the inductance and part is reflected back into circuit *1*. The equation for the energy absorbed by the resistor from the time at which the wave front arrived at the resistor, which time is taken as zero, to the time "t" is

$$W_R=P_1I_1\frac{L^2}{R}\frac{2Z_1}{(Z_1+Z_2)^2}A(1-e^{-2At}) \quad (16)$$

where

$$A=\frac{1}{L}\frac{Z_1+Z_2}{1+\frac{Z_1+Z_2}{R}} \quad (7)$$

These formulas are taken from Appendix II.

In studying the energy absorption by this type of absorber for different values of the resistance R, let us consider the case where the choke coil has a concentrated inductance of 3.2 milli-henries and the circuit *1* has a natural impedance $Z_1 = 300$ ohms. The velocity of the wave in circuit *1* is taken as 1000 ft. per micro-second, which is approximately the velocity on an overhead line.

Three cases will be considered as in Part I.

(1) $Z_2 = 10\ Z_1$ or 3000 ohms representing a transformer.

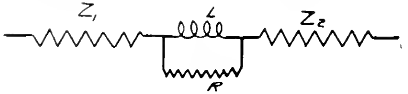


Fig. 14

(2) $Z_2 = Z_1$ or 300 ohms, the circuits having the same constants on both sides of the absorber.

(3) $Z_2 = \frac{1}{10}\ Z_1$ or 30 ohms, representing a cable.

In all cases the incident wave is taken with a vertical front, with a voltage P_1 and current I_1.

Fig. 15 shows the loss W_R with a wave of infinite length passing through the absorber from circuit $Z_1 = 300$ ohms to circuit Z_2. The energy loss is plotted in terms of the energy in 1000 ft. of the incoming wave as explained in Part I. The ordinates are, therefore,

$$\frac{W_R}{P_1 I_1 10^{-6}}$$

where W_R is the watt loss in the resistance, P_1 and I_1 respectively the voltage and current of the incoming wave. The abscissae give the resistance in terms of Z_1. The curves for $Z_2 = 10\ Z_1$ is omitted because of the small value of the ordinates.

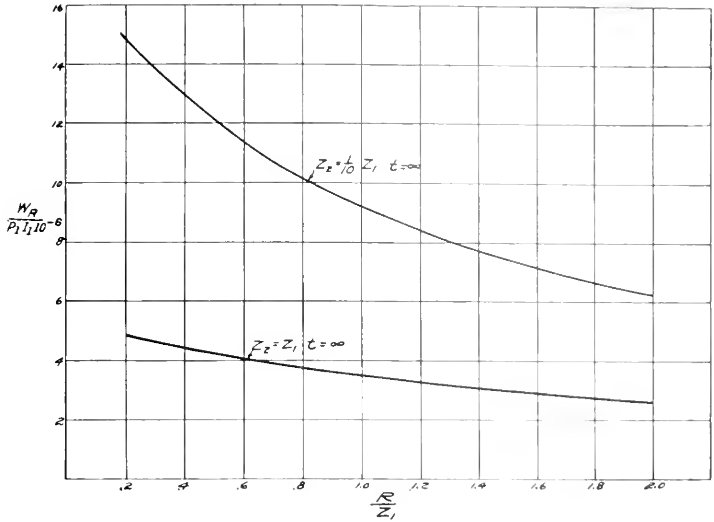
Fig. 16 shows how the total energy dissipation for a wave of infinite length varies with the inductance for a circuit $Z_1 = 300$ ohms and $Z_2 = 30$ ohms. The loss is directly proportional to the inductance.

The curves of Figs. 15 and 16 show that very low values of shunt resistance give the most dissipation for waves of infinite length. An infinitely long wave is not, however, dangerous except for a possible steepness of wave front. A continuously applied voltage corresponds somewhat to an infinitely long wave. Waves of comparatively short length may be dangerous because of steepness of wave front and also because a succession of such waves may produce dangerous local oscillations and potentials. We are therefore principally interested (from the energy standpoint) in absorbing the energy of waves of comparatively short length. Within certain ranges of R and L, the dissipation of energy is nearly as much for comparatively short waves as for infinitely long waves. For this reason, it is permissible in some cases, to use the equations of energy loss for infinitely long waves, in discussing comparatively short waves. This is the method used in the numerical example given later in this article.

Fig. 17 shows the time required for the loss W_R to reach 0.6 and 0.8 of its maximum value (that is, the value for a wave of infinite length) with an inductance $L = 3.2$ milli-henries and for a circuit $Z_1 = 300$ ohms and $Z_2 = 30$ ohms. Figs. 15 and 16 showed that the total energy dissipation for very long waves is greatest for very small values of R. Fig. 17 shows that the rate of energy dissipation is not so great for the very small values of R. For example, with $R = Z_1$ about 10 micro-seconds are required for the loss to reach 0.6 the maximum value, while with $R = 0.2 Z_1$ 28 micro-seconds are required for the loss to reach the same value. Therefore, for very short waves, where the rate of energy dissipation is important, the smallest values of R are not the most effective.

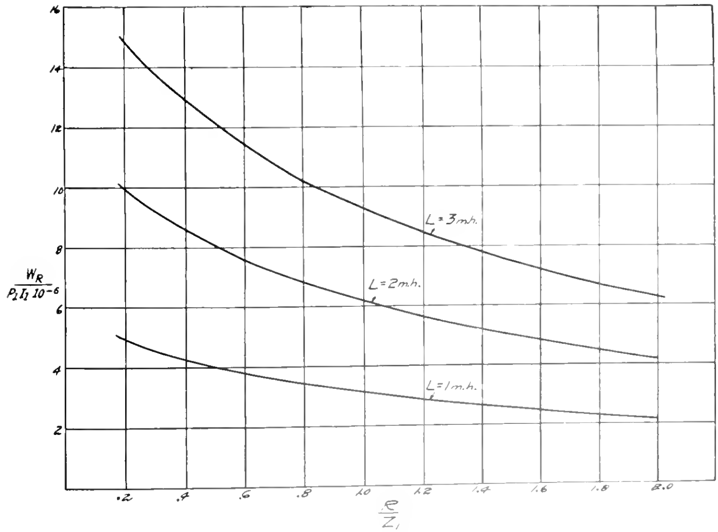
To determine the best values of R for waves of very short length, we will now consider two waves of 5000 and 10,000 ft. in length. Fig. 18 shows the loss W_R (plotted as before in terms of the energy of 1000 ft. of incoming wave) for a circuit $Z_1 = 300$ ohms and for three values of Z_2, with an absorber of inductance 3.2 milli-henries and rectangular incoming waves of 5000 ft. and 10,000 ft. in length. The curve for $Z_2 = 10 Z_1$ and $t = 10 \times 10^{-6}$ seconds is omitted. The inductance value has been chosen to make these energy absorption curves cover about the same range as those for the condenser-resistance absorber in Fig. 4. It is interesting to note that the inductance-resistance absorber is most effective for a wave passing from one circuit to another circuit of lower natural impedance, whereas the condenser-resistance absorber is most effective for waves in the opposite direction. These curves show that the resistance can be varied over a considerable range without greatly affecting the energy dissipation.

Fig. 19 shows how the loss W_R varies with L for a circuit $Z_1 = 300$ ohms and $Z_2 = 30$ ohms, with rectangular incoming waves of 5000 ft.



$Z_2 = \frac{1}{10} Z_1 \ t = \infty$
$Z_2 = Z_1 \ t = \infty$
$\frac{W_R}{P_1 I_1 10^{-6}}$
$\frac{R}{Z_1}$

Fig. 15



L = 3 m.h.
L = 2 m.h.
L = 1 m.h.
$\frac{W_R}{P_1 I_1 10^{-6}}$
$\frac{R}{Z_1}$

Fig 16

and 10,000 ft. length. Comparing this figure with Fig. 16, we see that the value of L does not have so much effect with short waves, and that the shorter the wave, the less the value of L which will allow efficient dissipation. An absorber that is effective for waves of 5000 and 10,000 ft. length, will be still more effective for shorter waves.

Figs. 20 and 21 show how the energy of the incoming wave of 5000 ft. length divides. W_R is the energy dissipated in the resistance, W_L the energy stored temporarily in the inductance, W_2 the energy transmitted to circuit *2* and W_r the energy reflected to circuit *1*. These curves are for a circuit $Z_1=300$ ohms and an inductance of 3.2 milli-henries. Fig. 20 is for $Z_2=\frac{1}{10}Z_1$ and Fig. 21 for $Z_2=Z_1$. All of the energies are plotted in terms of the energy of 1000 ft. of the incoming wave.

Fig. 22 shows the transmitted voltage wave P_2 and reflected voltage wave P_r when a rectangular wave P_1 comes to an absorber of inductance $L=3.2$ milli-henries and resistance $R=Z_1=300$ ohms. The voltage P_1 of the incident wave is taken as unity and the wave front of the transmitted wave is plotted for three values of Z_2, namely, $Z_2=10\ Z_1$, $Z_2=Z_1$ and $Z_2=\frac{1}{10}Z_1$. The complete transmitted and reflected waves are drawn only for $Z_2=Z_1$. The other waves are similar. Fig. 23 shows the same waves when there is no shunting resistance R. These waves have been taken very long in order to show the voltages reaching approximately their maximum value.

Fig. 24 corresponds to Fig. 11 and shows how the starting values of P_2 are affected by the value of shunt resistance. All conditions are the same as those in Figs. 22 and 23. Steep wave fronts are flattened out most when Z_2 is less than Z_1.

It will be interesting to work out a simple numerical example by applying the formulæ for traveling waves given in Appendix II.

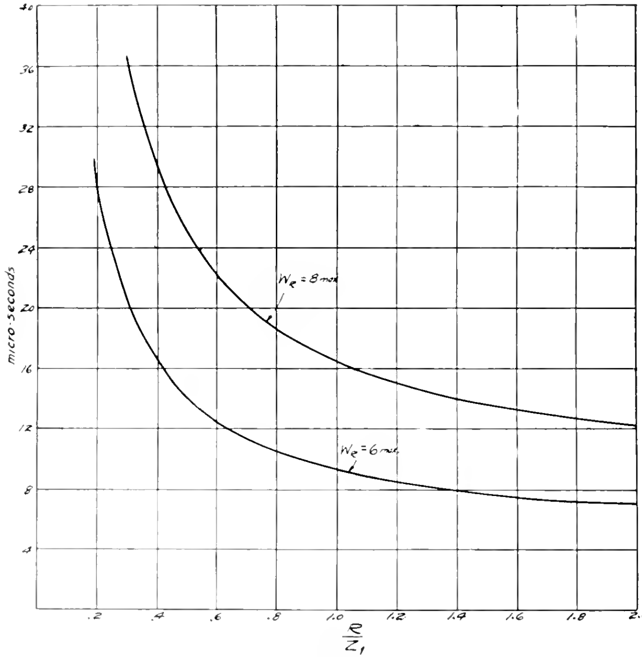


Fig. 17

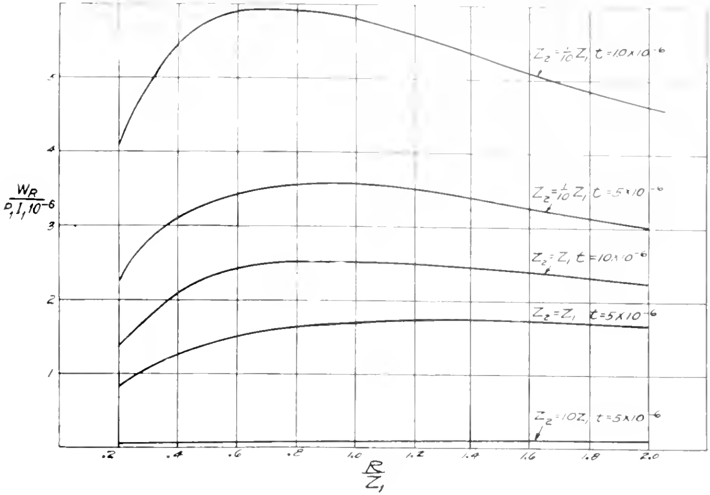

$Z_2 = \frac{1}{10} Z_1$ $t = 1.0 \times 10^{-6}$
$Z_2 = \frac{1}{10} Z_1$ $t = 5 \times 10^{-6}$
$Z_2 = Z_1$ $t = 10 \times 10^{-6}$
$Z_2 = Z_1$ $t = 5 \times 10^{-6}$
$Z_2 = 10 Z_1$ $t = 5 \times 10^{-6}$
$\frac{W_R}{P_1 I_1 10^{-6}}$
$\frac{R}{Z_1}$

Fig. 18

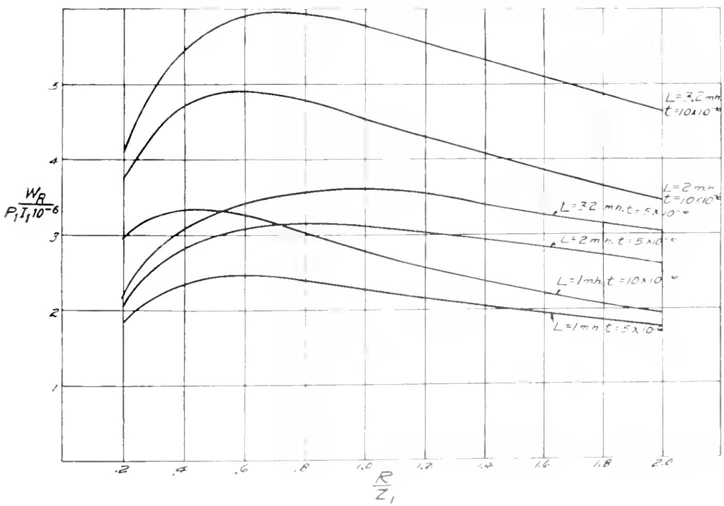

L = 3.2 mh. t = 10x10⁻⁶
L = 2 m.h. t = 10x10⁻⁶
L = 3.2 mh. t = 5x10⁻⁶
L = 2 mh. t = 5x10⁻⁶
L = 1 mh. t = 10x10⁻⁶
L = 1 mh t = 5x10⁻⁶
$\frac{W_R}{P_1 I_1 10^{-6}}$
$\frac{R}{Z_1}$

Fig 19

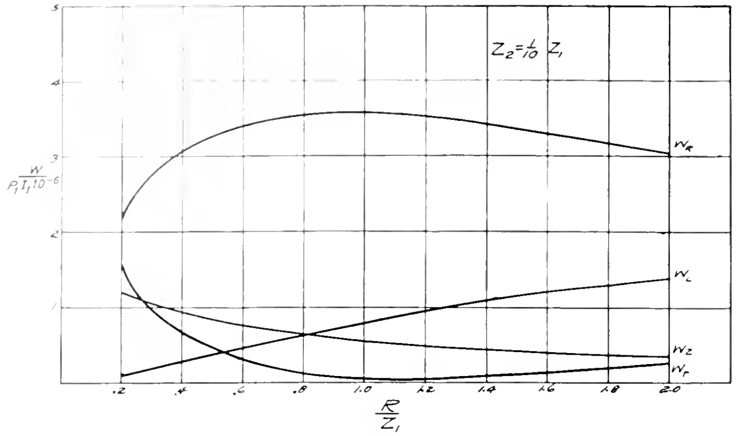


Fig. 20

It may be well to point out that at $t=0$ all the conditions are the same as if the resistance R alone were connected in series with the line, while final conditions are the same as if the resistance-inductance absorber were short-circuited. Let us assume

$$Z_1 = 500 \text{ ohms}$$
$$Z_2 = 2000 \text{ ohms}$$
$$L = 2 \times 10^{-3} \text{ henries}$$
$$R = Z_1 + Z_2 = 2500 \text{ ohms}$$

This value of resistance is chosen because it gives the maximum rate of dissipation of energy at $t=0$.

The incoming wave has

$$P_1 = 10^5 \text{ volts}$$
$$I_1 = 200 \text{ amperes}$$

The energy per thousand feet of the incoming wave is then 20 watt-seconds (taking the velocity as 1000 feet per micro-second).

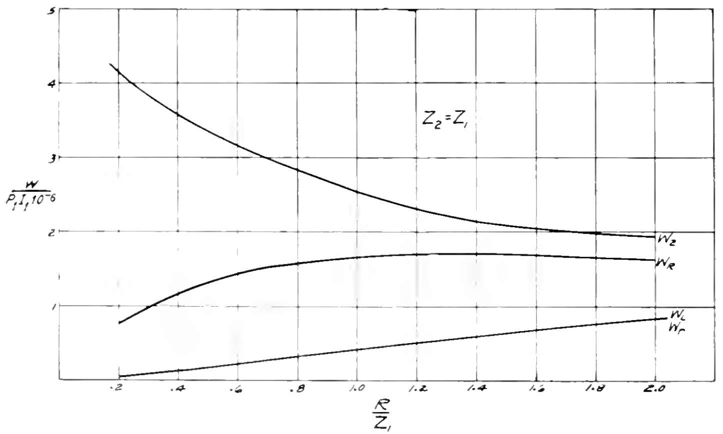


Fig. 21

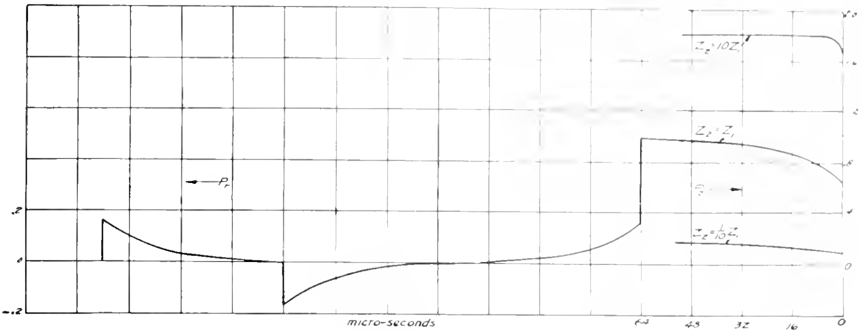


Fig. 22. Curves Based on Value of $P_1 = 1$

Substituting in formulæ (7) and (21), we have

$$A = \frac{2500}{2\times 10^{-3}}\,\frac{1}{2} = \frac{1}{16\times 10^{-7}}$$

$$\frac{L}{R}A = \frac{1}{2}$$

$$F = 10^5\times 2\times 10^2\times 2\times 10^{-3}\,\frac{10^3}{(25)^3\times 10^6} = .00256$$

The current I_2 of the transmitted wave goes from $200\;\frac{1000}{2500}\,\frac{1}{2} = 40$ at $t=0$ to 80 at $t=$ infinity. See (10).

The current I_1 of the reflected wave goes from $200\left(\frac{1500}{2500} + \frac{1000}{2500^2}\,\frac{1}{8\times 10^{-4}}\right) = 160$ at $t=0$ to 120 at $t=$ infinity. See (11).

If the absorbers were omitted, the energy of the incoming wave would be divided as follows: The part $\frac{4Z_1Z_2}{(Z_1+Z_2)^2} = 0.64$ would be transmitted, and the part $\frac{(Z_2-Z_1)^2}{Z_2+Z_1} = 0.36$ would be reflected, and the wave fronts would remain vertical. See (17) and (18) for $F=0$

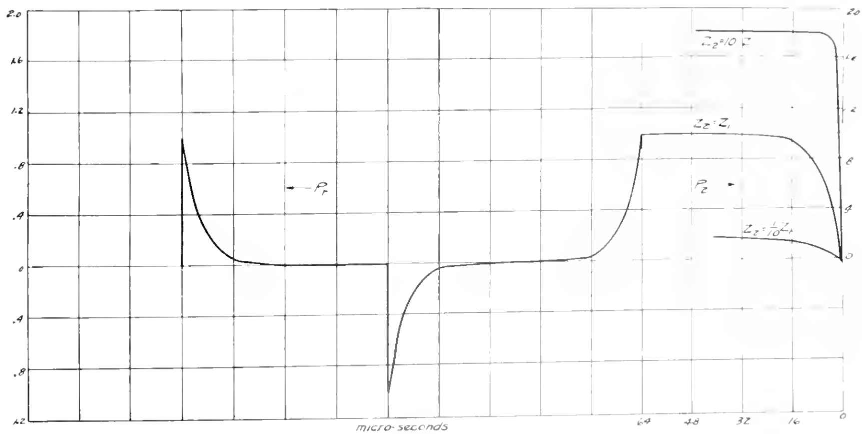


Fig. 23. Curves Based on Value of $P_1 = 1$

Comparing the action at the wave front by the absorber having $L=2 \cdot 10^{-3}$ henries shunted by $R=2500$ ohms with the action of the simple choke coil of the same inductance and referring to formulæ (17) to (20) and (31) to (33), we obtain the following tabulation of energies:

$R=\infty$	$R=2500$
Front	
$W_1=P_1I_1t$	$W_1=P_1I_1t$
$W_2=0.64P_1I_1t-15.36$	$W_2=0.64\ P_1I_1t-17.92$
$W_r=0.36\ P_1I_1t+8.96$	$W_r=0.36\ P_1I_1t+8.32$
$W_L=6.4$	$W_L=6.4$
$W_R=0$	$W_R=3.2$
Tail	
$W_L=6.4$	$W_L=6.4$
$\overline{W_2}=5.12$	$\overline{W_2}=2.56$
$\overline{W_r}=1.28$	$\overline{W_r}=0.64$
$\overline{W_R}=0$	$\overline{W_R}=3.2$

15.36 watt-seconds are taken from the fronts of the transmitted waves, 8.96 watt-seconds being reflected into circuit Z_1 and 6.4 watt-seconds stored in the inductance. If a resistance of 2500 ohms is connected in shunt with the inductance, then 17.92 watt-seconds are taken from the fronts of the transmitted waves, and of these watt-seconds 8.32 are reflected back into line Z_1, 6.4 are stored in the inductance and 3.2 are dissipated by the resistance. At the end of the wave, if the inductance is alone, of the 6.4 watt-seconds stored in it, 5.12 are returned to line Z_2 and 1.28 to line Z_1. If a resistance of 2500 ohms is connected in shunt with the inductance, then 2.56 watt-seconds are returned to line Z_2, 0.64 watt-seconds are returned to line Z_1 and 3.2 watt-seconds are dissipated in the resistance.

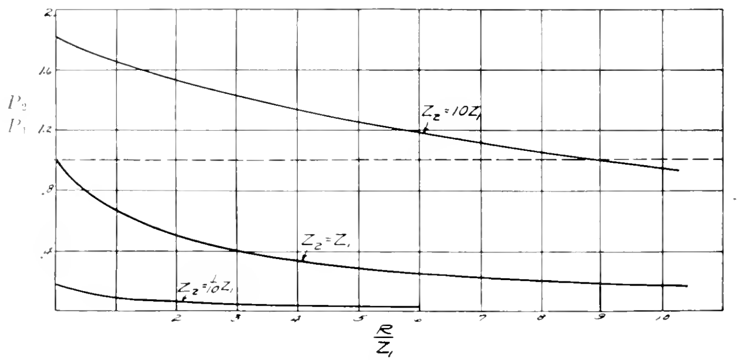


Fig. 24

The energies in the above tabulation have been taken when the phenomena at the fronts and tails of the waves were practically completed, and, therefore, as far as these phenomena are concerned, all the integrals have been taken with the upper limit equal to infinity. An idea of the length of time required to obtain these conditions can be formed by considering that, if W_R would continue at the same rate as at $t=0$, it would reach the final value after a time $t=\frac{1}{2.1}=80$ micro-seconds.

The tabulation shows that if no resistance is connected in shunt with the inductance,

We have seen that the energy of a thousand feet of the incoming wave is 20 watt-seconds; therefore the amount of energy dissipated in the resistance R at the front and tail of the wave is equivalent to the energy of 320 feet of the incoming wave.

Let us now repeat the calculation for the same wave traveling through the same circuits in the opposite direction. We then have

$$Z_1=2000 \text{ ohms}$$
$$Z_2=500 \text{ ohms}$$
$$L\ =2\times 10^{-3} \text{ henries}$$
$$R\ =2500 \text{ ohms}$$

The voltage of the incoming wave is again

$$P_1 = 10^5 \text{ volts}$$
$$I_1 = 50 \text{ amperes}$$

The energy per thousand feet of the incoming wave is now 5 watt-seconds (assuming as before a velocity of 1000 feet per micro-second).

A is again equal to $\frac{1}{16 \times 10^{-7}}$. See (7).

$F = 0.00256$ as before. (See 21).

The transmitted current I_2 goes from $50 \frac{4000}{2500} \frac{1}{2} = 40$ at $t = 0$ to 80 at $t = \text{infinity}$. See (10).

The reflected current goes from $50 \left(\frac{-1500}{2500} + \frac{4000}{(2500)^2} \frac{2500}{2} \right) = 10$ at $t = 0$ to -30 at $t = \text{infinity}$. See (11).

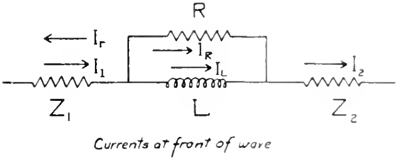


Fig. 25

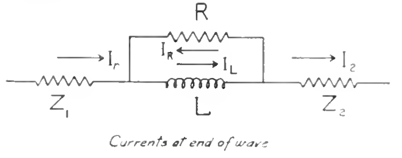


Fig. 26

Let us tabulate below the energies at the fronts and tails of the waves for two cases. First, when a simple inductance of 2×10^{-4} henries is connected between Z_1 and Z_2; second, when this inductance is shunted by a resistance of 2500 ohms. See formulæ (17) to (20) and (31) to (33), where, as before, the integrals are taken with the upper limit equal to infinity.

$R = \infty$	$R = 2500$
Front	
$W_1 = P_1 I_1 t$	$W_1 = P_1 I_1 t$
$W_2 = 0.64\ P_1 I_1 t - 3.84$	$W_2 = 0.64\ P_1 I_1 t - 4.48$
$W_r = 0.36\ P_1 I_1 t - 2.56$	$W_r = 0.36\ P_1 I_1 t - 5.12$
$W_L = 6.4$	$W_L = 6.4$
$W_R = 0$	$W_R = 3.2$
Tail	
$W_L = 6.4$	$W_L = 6.4$
$\overline{W}_2 = 1.28$	$\overline{W}_2 = 0.64$
$\overline{W}_r = 5.12$	$\overline{W}_r = 2.56$
$\overline{W}_R = 0$	$\overline{W}_R = 3.2$

In this case, when the inductance is alone, 3.84 watt-seconds are taken from the fronts of the transmitted waves and 2.56 watt-seconds are taken from the fronts of the reflected waves, making a total of 6.4 watt-seconds which are stored in the inductance. When the inductance is shunted by a 2500-ohm resistance, 4.48 watt-seconds are taken from the fronts of the transmitted waves and 5.12 watt-seconds are taken from the fronts of the reflected waves; of these, 6.4 are stored in the inductance L, 3.2 are dissipated by the resistance R. At the end of the wave, if the inductance is alone, of the 6.4 watt-seconds stored in it, 1.28 are returned to the line Z_2 and 5.12 are returned to the line Z_1; if the inductance is shunted by a 2500-ohm resistance, then of the 6.4 watt-seconds stored in the inductance, 0.64 are returned to the line Z_2, 2.56 are returned to the line Z_1 and 3.2 are dissipated in the resistance. The energy absorbed by the resistance at the front and tail of the wave is equal to the energy of 1280 feet of the incoming wave.

It will be noted that the actual amount of energy absorbed by the resistance is the same whether the wave travels from the circuit of lower natural impedance to the circuit of higher natural impedance, or vice versa. However, the "relative" absorption of energy, that is to say, the ratio between the energy dissipated in the resistance and the energy per unit length of the incoming wave is four times greater when the wave passes from the circuit of higher to the circuit of lower impedance than when the wave passes in the opposite direction.

This feature is characteristic of this type of absorber. In fact, the ratio between the energy dissipated in the resistance at the wave front and the energy in one micro-second of incoming wave is

$$\frac{P_1 I_1 \frac{2 Z_1}{(Z_1 + Z_2)^2} \frac{L^2}{R} A}{P_1 I_1 \times 10^{-6}} = \frac{2 L^2 A}{R (Z_1 + Z_2)^2} 10^6 \times Z_1$$

See (20).

The factor that multiplies Z_1 is the same whether the wave travels in one direction or in the opposite direction. Therefore, their "relative" absorption of energy at the front of the wave is proportional to Z_1. The same conclusion applies to the energy at the tail of the wave. This confirms the results as shown by the preceding curves.

It will be noted that in the case of the condenser-resistance, this "relative" absorption is proportional to Z_2, that is to say, the absorption of energy by the condenser-resistance is greater when the wave passes from the circuit of lower impedance to the circuit of higher impedance, whereas the absorption of energy by the inductance-resistance is greater when the wave passes from the circuit of higher impedance to the circuit of lower impedance.

Summary

We have reviewed the action of the condenser-resistance and of the inductance-resistance in connection with sustained oscillations and steep traveling waves, with special reference to the absorption of energy by the resistor connected either in series with the condenser or in shunt with the inductance. The assumptions made in dealing with sustained oscillations, rectangular waves, and concentrated reactance and resistance, while they facilitated the mathematical treatment are not inconsistent with the general characteristics of the phenomena.

We wish to point out that, while these absorbers have been generally conceived as a condenser or an inductance to which a resistor is added in series or in shunt, the best conception of their action is obtained if these absorbers are considered as resistors to which a condenser or an inductance is connected in series or in shunt to act as a switch, which automatically connects the resistor when an abrupt variation of energy occurs and automatically disconnects it when conditions are normal and the resistors are not needed.

We have shown the well known properties of the absorbers of minimizing the danger arising from the high frequency oscillations. We have stated that traveling waves may be dangerous due to a steepness of wave front and due to local oscillations and potentials which may be produced by a succession of short waves. We have found that high-frequency absorbers give very effective protection against such waves by dissipating the wave energy and flattening out the steep wave fronts. They are aided in this action by the dissipation that takes place in the line itself. They are a valuable adjunct to lightning arresters which are primarily protectors against waves of excess voltage. We have discussed the best values of resistance for each type of absorber and found that they cover a fairly wide range. The curves and discussion have dealt principally with a few particular cases but the general equations have been derived.

We have seen that the condenser-resistance gives the maximum absorption of energy when the wave passes from the circuit of lower impedance to the circuit of higher impedance, while the inductance-resistance gives the maximum absorption of energy when the wave passes from the circuit of higher impedance to the circuit of lower impedance. It is interesting to note that the condenser-resistance and the inductance-resistance give the same dissipation of energy when the ratio between the inductance of the choke coil and the capacity of the condenser is such that $\sqrt{\frac{L}{C}}=Z_2$, and the resistance $R=\sqrt{Z_1Z_2}$ is used in both cases. If the constants of the circuit are the same on both sides of the absorber, that is to say, if $Z_1=Z_2=Z$, then the condenser-resistance and the inductance-resistance produce the same absorption of energy when $\sqrt{\frac{L}{C}}=R=Z$.

In some cases, the use of both types of absorbers in combination may be advisable. Another article may be written later by the authors on the subject of the combinations of various types of absorbers.

APPENDIX II

The fundamental equations of a rectangular wave, passing from a circuit of natural impedance Z_1, past an inductance-resistance, to a circuit of natural impedance Z_2 (see Fig. 14) are

$$I_1=I_2+I_r \qquad P_1=I_1Z_1 \qquad (1)$$

$$I_2=I_L+I_R \qquad P_r=I_rZ_1 \qquad (2)$$

$$P_2=P_1+P_r-L\frac{dI_L}{dt} \qquad P_2=I_2Z_2 \qquad (3)$$

$$L\frac{dI_L}{dt}=RI_R \qquad (4)$$

where

P_1 and I_1 are respectively the voltage and current of the incoming wave.

P_2 and I_2 the voltage and current of the transmitted wave.

P_r and I_r the voltage and current of the reflected wave.

L the inductance of the choke coil (the resistance of the choke coil is assumed to be zero).

R	the value of the resistance in shunt with the choke coil.
I_L	the current through the choke coil.
I_R	the current through the resistance R.

From (2) and (4) we have

$$I_2 = I_L + \frac{L}{R}\frac{dI_L}{dt} \qquad (5)$$

Substituting in equation (3) and re-arranging, we have

$$\frac{dI_L}{dt} + I_L A = 2\, I_1 A \frac{Z_1}{Z_1+Z_2} \qquad (6)$$

Where

$$A = \frac{1}{L}\,\frac{Z_1+Z_2}{1+\dfrac{Z_1+Z_2}{R}} \qquad (7)$$

Integrating (6) gives,

$$I_L = I_1 \frac{2\,Z_1}{Z_1+Z_2}(1-e^{-At}) \qquad (8)$$

from (4)

$$I_R = \frac{L}{R}\frac{dI_L}{dt}$$

Therefore

$$I_R = I_1 \frac{2\,Z_1}{Z_1+Z_2}\,\frac{L}{R} A e^{-At} \qquad (9)$$

from (2)

$$I_2 = I_1 \frac{2\,Z_1}{Z_1+Z_2}\left(1 - \frac{L}{Z_1+Z_2} A e^{-At}\right) \qquad (10)$$

from (1)

$$I_r = I_1\left(\frac{Z_2-Z_1}{Z_1+Z_2} + \frac{2\,Z_1}{(Z_1+Z_2)^2} L A e^{-At}\right) \qquad (11)$$

The equations for the energies are (in watt-seconds or joules);
for the incoming wave

$$W_1 = P_1 I_1 t \qquad (12)$$

for the transmitted wave

$$W_2 = \int_0^t P_2 I_2\, dt$$

Therefore

$$W_2 = P_1 I_1 \left[\frac{4\,Z_1 Z_2}{(Z_1+Z_2)^2} t - L\frac{8\,Z_1 Z_2}{(Z_1+Z_2)^3}(1-e^{-At}) + AL^2 \frac{2\,Z_1 Z_2}{(Z_1+Z_2)^4}(1-e^{-2At})\right] \qquad (13)$$

for the reflected wave

$$W_r = \int_0^t P_r I_r\, dt$$

Therefore

$$W_r = P_1 I_1 \left[\frac{(Z_2-Z_1)^2}{(Z_1+Z_2)^2} t + \frac{4\,Z_1(Z_2-Z_1)}{(Z_1+Z_2)^3} L(1-e^{-At}) + \frac{2\,Z_1^2}{(Z_1+Z_2)^4} L^2 A (1-e^{-2At})\right] \qquad (14)$$

The energy stored in the choke coil is

$$W_L = \frac{1}{2} L I_L^2$$

Therefore

$$W_L = P_1 I_1 L \frac{2\,Z_1}{(Z_1+Z_2)^2}(1-e^{-At})^2 \qquad (15)$$

The energy dissipated in the resistance R is

$$W_R = \int_0^t R I_R^2\, dt$$

Therefore

$$W_R = P_1 I_1 \frac{L^2}{R}\,\frac{2\,Z_1}{(Z_1+Z_2)^2} A(1-e^{-2At}) \qquad (16)$$

If the wave is "long" and the time t is taken "late" enough to have the phenomena at the fronts of the wave practically completed, that is to say, if, at the time t, the choke coil offers practically zero impedance, then the integrals above may be extended from zero to infinity and the energies may be tabulated as follows:

$$W_1 = P_1 I_1 t \qquad (12)$$

$$W_2 = P_1 I_1 \frac{4\,Z_1 Z_2}{(Z_1+Z_2)^2} t - F\left(4\,Z_2 - \frac{Z_2}{Z_1+Z_2} LA\right) \qquad (17)$$

$$W_r = P_1 I_1 \frac{(Z_2-Z_1)^2}{(Z_1+Z_2)^2} t - F\left(2(Z_1-Z_2) - \frac{Z_1}{Z_1+Z_2} LA\right) \qquad (18)$$

$$W_L = F(Z_1+Z_2) \qquad (19)$$

$$W_R = F(Z_1+Z_2)\frac{L}{R}A \qquad (20)$$

Where

$$F = P_1 I_1 L \frac{2\,Z_1}{(Z_1+Z_2)^3} \qquad (21)$$

It will be noted that

$$W_1 = W_2 + W_r + W_L + W_R$$

and that the sum of the terms containing F (which terms affect the phenomena at the wave fronts) is zero. If no inductance were connected, then L would be 0 and F would be 0 and no deformation of wave fronts would occur; if no resistance R were used, but an inductance L were used, then we would have R = infinity and $A = \frac{Z_1+Z_2}{L}$.

At "the end of the wave," the energy stored in the choke coil is in part returned to the circuits Z_1 and Z_2, and in part is dissipated by R. In other words, the energy stored in the choke coil is discharged into a circuit which has two branches in parallel, one being R, the other being Z_1 in series with Z_2.

If we assume that the wave ends when the magnetic flux of the choke coil has reached its maximum value, that is to say, when the current I_L has reached its final value I_2, we have, during the discharge for the end of the wave and counting the time from the vertical end of the incoming wave,

$$-L\frac{dI_2}{dt} = RI_R = (Z_1+Z_2)I_2 \qquad (22)$$

$$I_L = I_R + I_2 \qquad (23)$$

$$I_2 = I_r \qquad (24)$$

and therefore

$$I_L = I_1\frac{2\,Z_1}{Z_1+Z_2}e^{-At} \qquad (25)$$

$$I_R = I_1\frac{2\,Z_1}{Z_1+Z_2}\,\frac{L}{R}Ae^{-At} \qquad (26)$$

$$I_2 = I_r = I_1\frac{2\,Z_1}{(Z_1+Z_2)^2}LAe^{-At} \qquad (27)$$

Figs. 25 and 26 show the directions of the currents at the front and at the end of the wave respectively.

The energy stored in the choke coil when I_L has reached the value I_2 is

$$W_L = P_1I_1L\frac{2\,Z_1}{(Z_1+Z_2)^2} \qquad (19) \text{ and } (21)$$

The energy returned to line Z_2 is

$$\overline{W_2} = \int_0^\infty P_2I_2dt = Z_2\int_0^\infty I_2^2\,dt$$

Therefore

$$\overline{W_2} = P_1I_1\frac{2\,Z_1Z_2}{(Z_1+Z_2)^4}L^2A \qquad (28)$$

The energy returned to circuit Z_1 is

$$\overline{W_r} = \int_0^\infty P_rI_r\,dt = Z_1\int_0^\infty I_2^2\,dt = \frac{Z_1}{Z_2}\overline{W_2}$$

Therefore

$$\overline{W_r} = P_1I_1\frac{2\,Z_1^2}{(Z_1+Z_2)^4}L^2A \qquad (29)$$

The energy dissipated in the resistance R is

$$\overline{W_R} = \int_0^\infty RI_R^2\,dt$$

Therefore

$$\overline{W_R} = P_1I_1\frac{2\,Z_1}{(Z_1+Z_2)^2}\,\frac{L^2}{R}A \qquad (30)$$

It will be noted that $\overline{W_R} = W_R$ for a "long" wave and that

$$\overline{W_L} = \overline{W_2} + \overline{W_r} + \overline{W_R}$$

Collecting F as before we tabulate the energies at the tail of the wave as follows:

$$\overline{W_L} = F\,(Z_1+Z_2) \qquad (19)$$

$$\overline{W_2} = F\frac{Z_2}{Z_1+Z_2}LA \qquad (31)$$

$$\overline{W_r} = F\frac{Z_1}{Z_1+Z_2}LA \qquad (32)$$

$$\overline{W_R} = F\,(Z_1+Z_2)\,\frac{L}{R}A \qquad (33)$$

Methods for the Production and Measurement of High Vacua

PART IX. PHYSICAL CHEMICAL METHODS

By Saul Dushman

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The present installment deals with electrical clean-up of gases at low pressures, more especially with effects observed in hot cathode devices and incandescent lamps. The theory of phosphorous clean-up in lamps is also discussed. The next installment, which will complete the series, will present in a brief form the results of the more important investigations that have been carried out at low pressures.—Editor.

ELECTRICAL CLEAN-UP OF GASES AT LOW PRESSURES

As mentioned in a previous connection, an ordinary discharge tube with cold electrodes becomes inoperative when the pressure is reduced to too low a value. In general, this occurs at pressures which range from 1×10^{-3} to 100×10^{-3} mm. of mercury, depending upon the nature of the gas and the maximum voltage of the source of current. The operation of such discharge tubes depends primarily upon the formation of positive ions by the disruptive action of the voltage; and the bombardment of the cathode by these positive ions causes the emission of electrons which in turn ionize more gas molecules, so that the discharge is apt to become quite unstable. In the preceding section we discussed clean-up effects in such discharges at relatively high pressures. Within the past few years, however, a type of vacuum tube has been developed in which conduction occurs by means of electrons emitted from an incandescent cathode. The pressure in these devices must be maintained at a low value, ordinarily below 10^{-2} bar (10^{-5} mm. approximately). Consequently it is of practical importance to consider the changes in gas pressure which are observed in the operation of such tubes. The study of these phenomena is also of theoretical importance because it throws light, as will be shown, on certain clean-up effects in vacuum type incandescent lamps.

Electron Emission Phenomena at Low Pressures[1]

The electron emission from a heated cathode increases with the temperature according to the equation, first derived by Richardson:

$$i=A\sqrt{T}\,\epsilon^{-\frac{b}{T}}$$

where i = electron emission per unit area, and A and b are constants for any given material. Dr. Langmuir has shown that the actual magnitude of this emission at any temperature, that is of the values of A and b in this equation, is extremely sensitive to the presence of slight traces of certain gases and the maximum value of the specific emission at any temperature is attained only in extremely good vacua. In the case of tungsten, the constants have the values:

$$A=23\times10^{9}$$
$$b=52{,}5000$$

where i = milliamp. per cm^2, and T is the absolute temperature. This gives the *maximum electron current* that it is possible to obtain from a unit area of tungsten at any definite temperature.

It was observed by Langmuir that in addition to this limitation due to temperature, there is also present, at very low pressures, a voltage limitation, due to a "space charge" produced by the electrons in the neighborhood of the cathode. The electron current is then limited by the anode voltage V, in accordance with a relation of the form:

$$i=kV^{\frac{3}{2}}$$

where k is a constant whose value depends upon the geometrical arrangement and shape of the electrodes. This relation gives the *minimum voltage* between anode and cathode at which a given electron current can be obtained in the particular tube, under good vacuum conditions.

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[1] The literature on this subject has become so extensive in the past few years that only a brief discussion has been considered ample in the present connection. For further references, consult the following books and articles:

(a) O. W. Richardson, "The Emission of Electricity from Hot Bodies," 1916.
(b) H. J. Van der Bijl, "Thermionic Vacuum Tube," McGraw-Hill Book Co., 1920.
(c) I. Langmuir, General Electric Review, *18*, 327 (May 1915), *23*, 503, 589 (June and July, 1920).
(d) I. Langmuir, Phys. Rev., *2*, 402, 450 (1913).
(e) S. Dushman, General Electric Review, *18*, 156 (March 1915).
(f) S. Dushman, Phys. Rev., *4*, 121 (1915).

Ionization Effects

When, however, the gas pressure exceeds a certain value (depending principally upon the nature of the gas and the geometrical dimensions of the device) some of the electrons no longer travel directly from the cathode to the anode. Collisions with gas

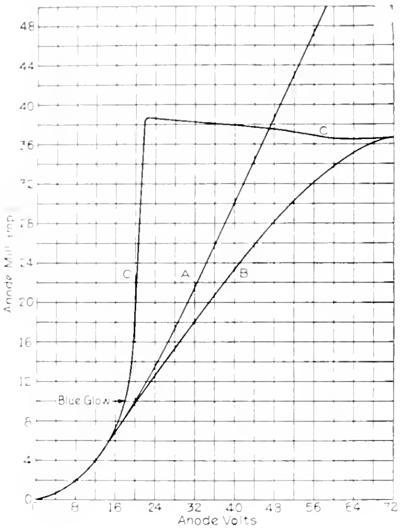

Fig. 68. Illustrating Effect of Mercury Vapor on Characteristics of Hot Cathode Tube

Curve *A*—Space charge limitation in good vacuum
Curve *B*—Space charge and temperature limitation
Curve *C*—Same filament temperature as Curve *B*, but in presence of mercury vapor at two bars

molecules occur, and if the anode voltage exceeds the so-called ionizing potential[2] positive ions are produced, which tend to neutralize a part or the whole of the negative space charge produced by the electrons and consequently the electron current reaches the saturation value corresponding to the temperature of the filament, at much lower voltages than when gas is not present.

These phenomena are illustrated by the following observations with a small hot-cathode high-vacuum rectifier (kenotron) in which a tungsten spiral was used as cathode, and a molybdenum cylinder (enclosing the spiral) as anode. To the bulb containing these electrodes was attached an appendix containing a small amount of mercury, and the whole arrangement was exhausted to a very high vacuum. By immersing the appendix in liquid air the pressure of the mercury vapor could be reduced to such a low value that no ionization effects occurred. Fig. 68 shows the characteristics of the tube under these conditions, at two different filament currents. It will be observed that at 1.35 amp. (Curve *A*), the electron current varied with the anode voltage in accordance with the 3/2 power relation. At 1.25 amp. the electron current increased at first in accordance with the same voltage law and then tended to reach the value 38 milliamp. corresponding to the emission for that particular temperature (Curve *B*).

On removing the liquid air from the appendix, so that the mercury attained room temperature and the pressure in the device reached the value of about 2×10^{-3} mm. (corresponding to the vapor pressure of mercury at this temperature), the characteristic obtained with the filament at 1.25 amp. was that shown in Curve *C*. At 18 volts a distinct blue glow appeared, and at 26 volts this glow extended practically all the way down the appendix. It will be observed that simultaneously with this appearance of blue glow, the electron current increased rapidly until it reached practically the same saturation value as that obtained under good vacuum conditions. That is, even at such a low pressure of mercury vapor, the space charge phenomena practically disappeared and the saturation electron emission corresponding to 1.25 amp. filament current was obtained at relatively low voltages.

Observations on Clean-up in Hot-cathode Devices

Similar phenomena are observed with all other gases in hot-cathode devices. At very low pressures the electron current varies with the voltage according to the 3/2 power law, but at higher pressures (ordinarily about one to two bars) blue glow appears as the voltage is raised above the ionizing potential and simultaneously with this blue glow the current increases rapidly, as shown in Curve *C*, Fig. 68, to the saturation emission at the given filament temperature. In the case of most gases this blue glow does not ordinarily persist very long, owing to clean-up effects that accompany the appearance of this glow, and consequently the

[2] While the subject of ionization potentials is discussed in a subsequent section, it may be stated that for each gas it has been observed there exists a definite voltage at which the electrons acquire sufficient velocity to produce positive ions by collisions with gas molecules. These voltages have been measured for a number of gases and metallic vapors, and they are found to vary from about 25 volts in the case of helium to approximately 4 volts in the case of the alkali metals.

electron current decreases again gradually until it attains the limiting value corresponding to the space charge.

These clean-up phenomena that are observed in hot-cathode devices are extremely interesting, and they are of great technical importance. The experimental evidence which has been obtained in this laboratory and by other investigators points to the conclusion that these effects are primarily due to the formation of ions by collisions between electrons and gas molecules. There is little or no evidence for any electrical clean-up below ionizing potentials.

Experiments along this line carried out in this laboratory for the past few years have shown that the factors governing this clean-up are quite complex. In general, the rate of clean-up shows a tendency to increase with the anode voltage and with the electron current. In addition to these factors, the condition of the glass walls and the previous history of the bulb exert a profound effect on the rate of clean-up. The disappearance of gas by electrical clean-up is observed even at the very low pressures where space charge effects are present and blue glow is therefore absent. Numerous observations in connection with hot-cathode devices, such as are made up in this laboratory, have confirmed this conclusion. Thus, a kenotron (hot-cathode rectifier) may be sealed off at 0.05 bar and by subsequently operating it with a current of a few milliamperes at 120 to 240 volts, the pressure will be found to decrease to 0.01 bar or less.

At any given electron current the residual gas pressure in the sealed off tube reaches an equilibrium value which increases with the electron current. Part of this increase is probably due to an increased rate of evolution from metal parts and glass walls until equilibrium is attained with the increased rate of clean-up. The pressure may thus be found to vary from 0.01 to as low as 0.0001 bar, depending upon anode voltage and electron current. Similar effects have been observed with the ionization gage[3] in using it to measure low pressures of chemically active gases, such as nitrogen, hydrogen, and oxygen. That this clean-up is not due in these cases to purely chemical reactions at the surface of the tungsten filament is easily shown by taking off the anode voltage, when the clean-up practically ceases. Moreover this clean-up also occurs with the inert gases argon and helium.

[3]General Electric Review, 23, 874 (1920).
Physical Review, 17, 7 (1921).

A preliminary account of some recent observations made by Mrs. M. Andrews, Mr. Huthsteiner, and the writer on this subject may be of interest in this connection. In these experiments a tube containing two adjacent tungsten filamants was used, so that either filament could be made cathode, and the rate of clean-up was investigated in the case of argon and nitrogen. Gas from a large reservoir was allowed to flow continuously through this tube at practically constant pressure, and the rate of clean-up was determined by collecting the gas after it left the tube. The pressures used in most of the experiments were so low that no blue glow effects were observed, and during any one set of observations both the electron current and the anode voltage were maintained constant. The magnitude of the current was varied in different runs from a few micro-amperes to several milliamperes, and the anode potential was varied from 25 to 250 volts. The rate of clean-up was observed in these experiments to increase almost linearly with increase in pressure. With electron currents below a milliampere, the rate of clean-up also varied linearly with the current, but showed a tendency to increase much less rapidly with electron currents exceeding this value. At anode voltages in excess of 25, the rate of clean-up was observed to be practically constant and independent of the voltage. With freshly baked out glass bulbs, the fatigue effects observed were quite pronounced. On covering the glass surface inside with a tungsten deposit (by evaporation of one of the filaments) the rate of clean-up was found to increase considerably, and much more gas could be cleaned up before fatigue effects occurred. The rate of clean-up of argon was found to be about half of that of nitrogen under otherwise similar conditions.

The following observations were made on a system consisting of a five-inch bulb containing two adjacent tungsten filaments to which was attached an ionization gage. The volume of the arrangement was about 1200 cm³. After a thorough exhaust on the condensation pump, followed by a flashing of the filaments at a high temperature, argon at a pressure of 1.35×10^{-3} mm. of mercury was let into the system and the whole sealed off the pump. One of the tungsten filaments was then made cathode and raised to the temperature necessary to give an electron emission of five milliamperes. With 250 volts on the other filament as anode, the pressure indicated in Table I were obtained at different intervals of time

TABLE I

Time t minutes	Pressure mm. × 10^{-3}	$k = \frac{1}{t} \log (P_0/P)$
0	1.35	
2	1.2	0.0255
4	1.05	0.0273
15	0.65	0.0212
27	0.36	0.0213
		Avg. = 0.0238

The constancy of k in the last column shows that the rate of clean-up at any instant was proportional to the pressure.

Observations were made in the same manner with nitrogen. In one experiment, using 5 milliamp. and 250 volts, the nitrogen cleaned up from a pressure of 8×10^{-3} mm. to 1×10^{-3} mm. in 36 minutes. In all these cases, if after cleaning up a certain amount of gas, more gas was let into the bulb, the rate of clean-up was observed to be much lower.

Regarding the mechanism of this clean-up, it is difficult to draw any positive conclusions. In the foregoing experiments there was no evidence to show that the gas was cleaned up at the cathode, as for instance by the formation of WN_2. This would certainly not be true in the case of argon; the gas was most probably driven into the walls. Subsequent heating rarely caused the evolution of as much gas as had been cleaned up, so that the ions must penetrate the glass quite deeply.

Observations similar to those mentioned have been made by other investigators working with hot-cathode devices. Thus W. H. Eccles, in a discussion on thermionic valves,[4] makes the following very interesting comments regarding clean-up effects:

"Many interesting phenomena are observed with the traces of residual gases always present even in the hardest of tubes. After running for some time with a given electron current to the positive electrode and a given voltage, a steady value for the pressure of the residual gas may be reached. If now the voltage is increased, but not sufficiently to overheat the positive electrode, the tube will harden, i.e., some of the residual gas will be absorbed. On the other hand, if the voltage is reduced, and particularly if the filament is simply heated without any voltage being applied to the positive electrode, the amount of residual gas will increase.

"These effects are well known to radiologists and various suggestions are put forward in explanation. But from the point of view of the development of the high-power valves, the whole problem requires careful investigation.

"The fact that an increasing voltage at the positive electrode hardens the valve leads to the conclusion that the effects are due to the action of the ionized gas. At these voltages the ions are positive, and their observed disappearance must be due to their being driven into the hot filament, or into the walls of the containing vessel. If they are driven into the filament, how are they retained with the filament at 2,000 deg. C.? Is any chemical action involved, or is it the same process as the occlusion in the positive electrode? Or is it only the walls of the containing vessel that absorb the ions?

"A suggestion has been put forward by Dr. G. B. Bryan of the Physics Laboratory, at Royal Naval College, Greenwich, that the occlusion of the gases and the emission of positive ions from metallic surfaces at moderate temperature are closely related. He visualizes the process as follows: Some proportion of the gas to which the electrodes are exposed will probably be ionized hydrogen. A positive hydrogen ion is a very small heavy projectile with considerable powers of penetration. On striking the surface of a solid it will pass through the outer surface and pick up an electron, so becoming neutral. Now, however, it is a large body entrapped in among the atoms of the metal and unable to escape under ordinary conditions. But at moderate temperatures the electrons may be shed again, and the positive ion, being no longer encumbered by the outlying electron, can escape, so constituting the positive emission. One peculiar fact has frequently been observed by Dr. Bryan when exhausting a valve, viz., that a small liberation of occluded gas will give rise to a greater tendency to arcing than the introduction of a much greater quantity of ordinary air. If the gas liberated from the electrodes is already ionized, the observation is immediately explained.

"This theory is a very interesting one, and is one on which some light could be thrown by the entire removal of all traces of hydrogen. At present, however, it has never seemed possible to do this, as such extremely small quantities are involved; and possibly other ionized gases may be entrapped in the

[4] The Radio Review, 1, 26 (1919).

same way. If it is the outer electron that is lost, this would seem to be quite possible."

That the positive ions attain, under even moderate voltages, velocities which are much greater than those possessed by the corresponding molecules at ordinary temperatures, has already been pointed out in the discussion of electrical clean-up at higher pressures.[5] It is therefore interesting to observe that Eccles and Bryan also consider that this may be a possible explanation of the observed clean-up effects in hot-cathode devices.

On the other hand, in a very recent paper by A. Ll. Hughes[6] another explanation has been made which is to a certain extent equally probable. In these experiments the electrical clean-up of nitrogen and hydrogen was studied in a tube containing as cathode a platinum filament coated with BaO and SrO. In most of the experiments the whole tube was kept immersed in liquid air and the electron current was maintained constant in any one set of measurements. The rate of clean-up was found to decrease gradually during any run, owing to gradual saturation of the walls of the tube (as in the experiments before mentioned). The initial pressures used in these experiments varied from 50×10^{-3} mm. to 2×10^{-3} mm. of mercury. The conclusions as stated by Hughes are as follows:

"For hydrogen, no disappearance was obtained unless the electrons had energy above 13 volts. The rate of disappearance rose rapidly as the energy of the electron was increased to about 70 volts, after which no rapid change was noted (the rate appeared to diminish somewhat when the energy of the electrons was raised from 150 to 300 volts). For nitrogen, the rate of disappearance was at first much less than for hydrogen, but when the energy of the electrons was raised sufficiently (roughly 200 volts) the rate of disappearance of the nitrogen exceeded that for hydrogen."

In explanation of the mechanism of clean-up Hughes concludes that "this disappearance is due to the splitting of the molecules into atoms when electrons collide with the molecules, and these atoms condense on the adjacent surfaces particularly if they are cold." This explanation would account for the observations made in the experiments of Mrs. Andrews and Huthsteiner that a charging up of the tungsten deposit on the walls, with either positive or negative potentials, produced no effect on the rate of clean-up of nitrogen. On the other hand, such an explanation could obviously not account for the clean-up of argon. Hughes has also calculated the ratio between the number of molecules disappearing and the number of

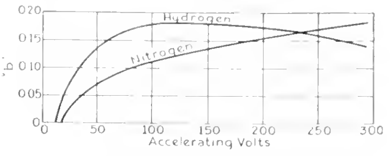

Fig. 69. Hughes' Experiments on Clean-up of Gases. Variation with voltage in the ratio (b) of the number of molecules clean-up to the number of collisions between electrons and molecules

collisions between electrons and molecules. Fig. 69 taken from his paper gives the relation between the value of this ratio (designated *b*) and the anode voltage for both nitrogen and hydrogen. It is seen that with approximately 250 volts on the anode, about one molecule disappeared for every six collisions, and presumably this molecule disappeared in the form of atoms. The theory that collisions between electrons and molecules may not only lead to the formation of ions but also to a dissociation of these molecules is extremely suggestive and may be of satisfactory explanation of the clean-up effects in some cases, but it is hardly possible that it is of general application.

Clean-up and Glow Phenomena

The disappearance of gas in hot-cathode devices has also been discussed at considerable length in two recent papers by the research staff of the General Electric Company, Ltd., London.[7] After discussing the previous work on clean-up phenomena in electrical discharge tubes[8] and Langmuir's work on purely chemical clean-up, the writers point out the effect of gas in eliminating space charge, as has already been described in the foregoing, and lay special stress upon the appearance of the glow as an essential factor for the occurrence of clean-up. Accordingly they have made very careful measurements of the potentials at which this glow occurs. "The first observations," it is stated, "proved that the glow potential is independent of the temperature of the filament and of the thermionic emission from it in wide limits. If there is no thermionic emission, the glow does not appear of course until the spark

[5] General Electric Review, *24*, 441 (May, 1921).
[6] Phil. Mag., *41*, 778 (1921).
[7] N. R. Campbell and J. W. H. Ryde, Phil. Mag., *40*, 585 (1920). N. R. Campbell, Phil. Mag., *41*, 685 (1921).
[8] See Part VIII of this series, May 1921, p. 436.

potential of the gas is reached, but the change from this condition to that in which the glow occurs at the very much lower potential obtained with a hot-cathode is so rapid that it could not be determined certainly whether the change was continous or discontinuous. Once the lower value is obtained, no further change occurs even if the thermionic emission is increased 100-fold. There is no evidence that the glow potential depends at all on the thermionic emission, so long as it is great enough to give at all a glow potential distinct from the spark potential. On the other hand, the glow potential depends greatly on the pressure, and on the nature of the gas."

Fig. 70 shows the relation obtained in this investigation, between the pressure and the glow potential for different gases. It will be observed that the potentials are plotted against the reciprocal of the pressures. The argon used contained five per cent nitrogen. The curves for hydrogen show the effects of slight traces of impurities. The glow potentials observed with increasing voltages were invariably somewhat higher than those observed with decreasing voltages, the maximum difference being obtained in the case of argon where it was about 10 volts at a pressure of 5×10^{-3} mm. of mercury.

In the case of mercury vapor the glow potential was observed to be always 32.5 volts, "whatever the nature of the gas with which it is mixed." Furthermore the addition of any impurity to a gas was often observed to decrease the glow potential below that of either of the constituents.

An important distinction is drawn by these investigators between the glow potential and that required for ionization. "It is clear that the glow potential is not, like the ionization potential, a direct property of the individual atoms of the gas, it must also be a function of their mode of reaction with each other or with the walls of the vessel; for the glow potential is not, like the ionization potential, independent of the pressure. There is no evidence, therefore, that the glow represents a new form of ionization of the individual atoms."

Some interesting observations are recorded by Campbell and his associates on the rate of disappearance of different gases in the presence of a glow discharge. In the case of CO, it was found that the gas cleaned up in consequence of the reaction, $2CO = C + CO_2$, the carbon dioxide formed being adsorbed on the glass walls. The complete elimination of mercury vapor is essential for the occur-

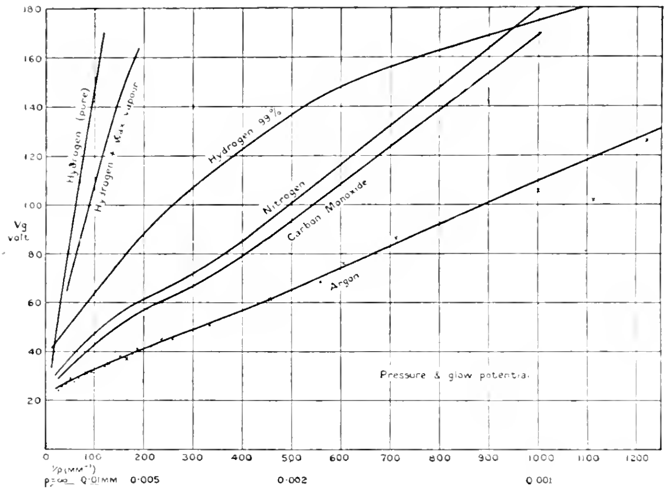

Fig. 70. Relation between Pressure and Glow Potential for Various Gases

rence of this reaction. "If mercury vapor is completely removed, the disappearance continues until the discharge stops, owing to the rise of the glow potential—at any rate, if a potential greater than 300 volts is not employed. If fresh CO is admitted, it disappears again under the discharge at a rate apparently unchanged; a limit to the absorption has not been found, although a quantity has been adsorbed equal to at least five times that representing a monomolecular layer on the walls." On baking the vessel to over 330 deg. C., the greater part of the gas was re-evolved, mostly as CO_2.

Nitrogen was observed to disappear in the same manner as does carbon monoxide, "in apparently unlimited quantities." This is accompanied by some decrease in the filament diameter and a blackening of the bulb. Probably WN_2 is formed as has been shown by Langmuir,[9] although Campbell seems inclined to believe that the tungsten is cathodically spluttered off the filament and covers the nitrogen which is adsorbed on the glass.

The rate of clean-up of argon was observed to be less than one-fifth that of nitrogen, and at the same time rapid blackening of the bulb occurred. "In both nitrogen and argon there is the intimate connection between cathode spluttering and absorption of gas which Vegard[10] has noted in the discharge without an incandescent cathode."

The observations with hydrogen in the absence of a discharge were in agreement with Langmuir's observations on the formation of atomic hydrogen.[11] Campbell finds, however, that in the presence of a discharge the rate of clean-up is much less than that obtained because of purely thermal dissociation.

Very interesting observations are recorded on the effect of passing a discharge in mercury vapor. In an otherwise thoroughly exhausted glass bulb, it was observed that under these conditions *hydrogen is liberated* from the walls. The fact that the discharge may evolve gas from the walls instead of causing it to disappear had already been noticed by Campbell as occurring to some extent in nitrogen, CO, and argon. In the presence of mercury vapor this phenomenon is extremely marked.

"And it should be noted that the gas thus liberated cannot be liberated by mere heating of the walls to their softening point; gas can be attached to the walls in some such way that it can be liberated by the discharge but not by heating. Of course, the attachment may consist of chemical combination; it is possible that glass contains hydrogen chemically combined, probably as water. But it should be observed that the hydrogen liberated, if piled up on the glass, would form a layer at least 25 molecules thick; some of it must therefore have come from a layer at least 25 molecules deep. Since the potential driving the discharge in these experiments was often as low as 50 volts, it is hardly to be expected that the electrons or ions could penetrate so far into the glass simply in virtue of the energy which they receive from the discharge. It seems easier to believe that a layer on the surface, subject to the action of these particles, is constantly renewed by diffusion from within."

The conclusions drawn by Campbell from his experiments are as follows:

"(a) All gases can be made to adhere to glass by the discharge in such a way that part, at least, can be restored by heating the glass.

"(b) The amount of gas that can be made so to adhere depends on the nature of the gas and on the state of the glass

"(c) The adhesion is not due primarily to chemical reaction, although such reaction (as in the conversion of CO to CO_2) may aid adhesion by converting the gas into another which adheres more readily.

"(d) The discharge can also liberate gas from the walls, doubtless by bombardment of the charged particles, and some of the gas so liberated cannot be liberated by heating the glass to the softening point.

"(e) The limit in the disappearance of the gas is reached when the rate at which gas is caused to adhere to the glass by the discharge becomes equal to the rate at which it is liberated by the bombardment."

The results of some experiments carried out in this laboratory are of interest in connection with these observations obtained by Campbell and his associates. That the clean-up effects are more pronounced in the presence of blue glow is undoubtedly true but, as already mentioned, the rate of electrical clean-up in hot-cathode devices is quite appreciable even at low pressures where the voltages used are below the glow potential. Again, the actual values of the glow potentials as given in Fig. 70 are probably dependent upon the form of the electrodes and the vessel, a conclusion which is also expressed by Camp-

[9] J. Am. Chem. Soc., *35*, 931 (1921).
[10] Ann. d. Phys., *50*, 769 (1916). See also Part VIII of this series, May 1921, p. 436.
[11] J. Am. Chem. Soc., *37*, 1161 (1915).

bell. Thus, the glow potential for mercury at 2×10^{-3} mm. is given by the latter as 32.5 volts, whereas, as stated above, concerning experiments carried out in this laboratory with a different construction of hot-cathode tube than that used by Campbell, blue glow has been observed at as low as 18 volts.

With regard to the relation between blue glow potential and electron emission, Mrs. Andrews[12] has observed that in the case of both argon and nitrogen the voltage required for the appearance of blue glow shows a tendency to decrease with increase in emission. At higher pressures it is possible to observe two glow potentials; at the lower of these, blue glow appears below the anode, and at the upper voltage the glow occurs both above and below the anode. Furthermore, with 250 volts on the anode, it was observed that the electron emission at which blue glow appeared varied approximately inversely with the pressure. Thus, at 45×10^{-3} mm. of argon, the electron emission required to produce blue glow was about 0.45 milliamp., whereas at 4×10^{-3} mm. the necessary emission was about 1.4 milliamp. In these measurements an ionization gage was used, with the inner filament as cathode and the other one as anode. At the same time the positive ion current was measured to the cylinder surrounding both filaments, and it was observed that this current was approximately the same in all cases when blue glow appeared. This means that for the appearance of glow in any device it is apparently necessary to have a certain density of positive ions. This conclusion would also be in accord with the observation mentioned previously that the electron current required for blue glow to appear varies inversely as the pressure.

Electrical Clean-up Phenomena in Incandescent Lamps

The observations discussed in the previous section have a fundamental significance from the point of view of the clean-up effects observed in vacuum type incandescent lamps.

In European practice it is customary to exhaust lamps to a very high degree of vacuum, the residual gas pressure being usually less than one bar. Care is taken to eliminate water vapor as much as possible by a thorough baking out of the glass, and the filaments are flashed on the pumps. On the other hand, in this country various economic considerations have led to greater and greater speed of production in all lines, not excluding that of lamp manufacture. Consequently the period of exhaust has been reduced, and at present it is the normal practice to complete the whole exhaust operation in a period which may vary from five minutes to as low as one-half minute. In this short period of time the pressure is reduced from atmospheric to a few bars, the glass is raised to a high temperature to eliminate as much water vapor as possible and the lamp sealed off.

It is evident that under these conditions there must remain in the lamp a considerable amount of residual gas, to which must be added the gas that is subsequently evolved on lighting the filaments. As a matter of fact, the residual gas pressure in actual practice varies from as low as one bar to over 100 bars, depending upon the nature of the exhaust process used. In view of the fact, which has been known for a long time, that the life of an incandescent lamp is considerably increased by improvement in vacuum and through elimination of water vapor, it has therefore been necessary to devise methods by which the residual gas can be cleaned up.

The most usual method of attaining this result is that suggested by Malignani in 1894. As used in the days of the carbon filament lamp,[13] "this process, in its most perfect form, consisted in distilling into the bulb a small amount of some such substance as arsenic, sulphur, iodine, or phosphorus. At the instant when one of these vapors was introduced, a high current was passed through the filament, the lamp being closed from the pump. In case of incandescent lamps where the voltage is above 50 for a fair brilliancy of filament, a blue discharge passes through the bulb and this blue quickly disappears when such vapors are introduced."

Further investigation, notably in this laboratory, showed that during the disappearance of blue glow there occurred a considerable improvement in vacuum. It was furthermore observed that this blue glow and clean-up also occurs if no phosphorus is used. "In improving the vacuum this latter way, however," states Dr. Whitney, "it is known that the filament is injured and apparently a part of its material has been vaporized. The process soon causes blackening of the lamp by carbon." The connection between blue glow and Edison currents in carbon lamps is also mentioned in the same paper.

[12] A complete account of these experiments will be published in the near future.

[13] W. R. Whitney, Trans. Am. Inst. Electrical Eng., 31, 921 (1912).

It was observed that if a platinum plate is sealed into a lamp and charged positively, a continuous current can flow to it from the negative half, or end of the filament, but not from the positive end. The current was found to vary with gas pressure and also the relative location of the plate in the lamp. At that time, of course, the phenomena of electron emission from heated filaments had not been studied thoroughly and for this reason no satisfactory explanation of the Edison effect could be given.

While in the older process the phosphorus was distilled into the lamp from a top tube with simultaneous flashing of the filament, the present process consists in coating the wire with an alcholic suspension of red phosphorus and some salt (to prevent subsequent blackening by evaporated tungsten). After the lamp is exhausted and sealed off, it is flashed with gradually increasing voltage, and as the phosphorus is volatilized from the filament, blue glow occurs and the residual gases are cleaned up.

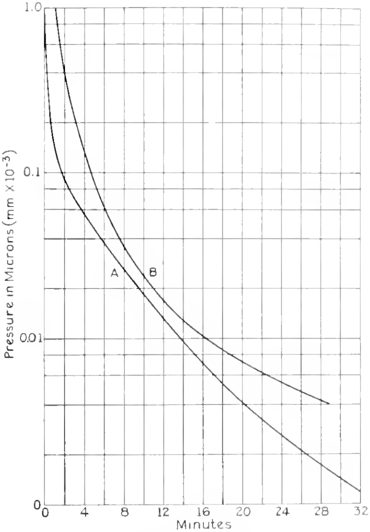

Fig. 71. Clean-up of Residual Air in 100-watt, 120 volt "Ungettered" Lamp

A—Initial pressure, 1.33 bar (1 micron)
B—Initial pressure, 6.67 bar (5 microns)

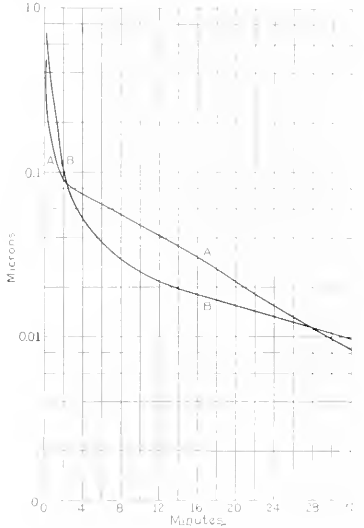

Fig. 72. Clean-up of Residual Air in 100-watt, 120-volt "Gettered" Lamp

A—Initial pressure, 10 microns
B—Initial pressure, 5 microns

The observations on electron emission and clean-up effects in hot-cathode tubes obviously throw considerable light on this phenomenon. The negative end of the filament emits electrons, and under the influence of the positive voltage produced by the other end of the filament the residual gas is ionized. Hence the appearance of blue glow. The positive ions are, then, cleaned up rapidly by the action of the voltage, in the same manner as has already been described, and the blue glow disappears.

The phenomena in tungsten lamps are similar to those observed in carbon lamps.

Before discussing the theories that have been suggested in explanation of the function of phosphorus in cleaning up residual gases, it is of interest to mention some of the experimental results that have been obtained by Mr. Huthsteiner and the writer on the rate of clean-up of gases in lamps under various conditions. Fig. 71 shows the clean-up of residual air in a regular type 100-watt 120-volt lamp in which no phosphorus or other clean-up reagent was used. An ionization gage attached to the lamp was used to measure the pressure. In lamp practice, any substance put on the wire or in the lamp for the part [illegible] in prolonging the vacuum or preventing blackening is known as a "getter." In these experiments therefore, of which the results are given in Fig. 71, the lamps were ungettered. Before introducing the air at the desired initial pressure, the lamp and ionization gage were well exhausted by baking out at 360 deg. C. for one hour on the pump and flashing the filaments to a high temperature, thus eliminating gases occluded in the glass walls and filament; the electrodes in the gage were also well bombarded. Curve *A* shows the rate of clean-up with an initial pressure of 1.33 bar (1 "micron,"[14] and Curve *B* with an initial pressure of 6.67 bar (5 microns). The initial flash of blue glow disappeared in a fraction of a minute, and as will be observed from the curves most of the gas cleaned up in this period. The subsequent rate of clean-up was not as rapid. The flashing voltage used was 156 volts, corresponding to 130 per cent of the normal operating voltage.

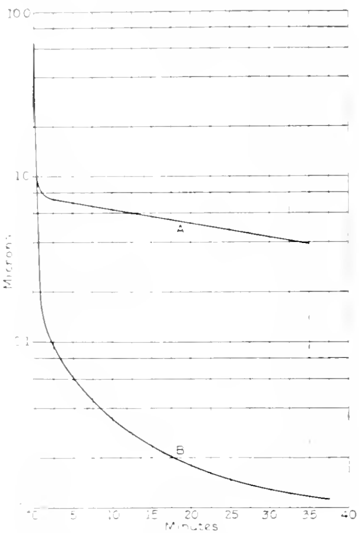

Fig. 73. Clean-up Argon (Curve *A*) and Air (Curve *B*) in 100-watt 120-volt Phosphorous Gettered Lamp. Flashed at 144 volts

Fig. 72 shows the results obtained with a similar lamp in which red phosphorus was used as getter. In this case the lamp and gage were exhausted as before, then air was let in, the lamp removed from the pump, and a suspension of red phosphorus in alcohol painted on the leads just below the filament. The combination was then re-exhausted, given a five-minute bake out at 360 deg. C. and sealed off. On flashing at 156 volts, the leads heated up sufficiently to voltalize the phosphorus and the clean-up curves shown in Fig. 72 were obtained.

In these cases, also, most of the gas cleaned up during the period of blue glow, and as will be seen by comparing these results with those

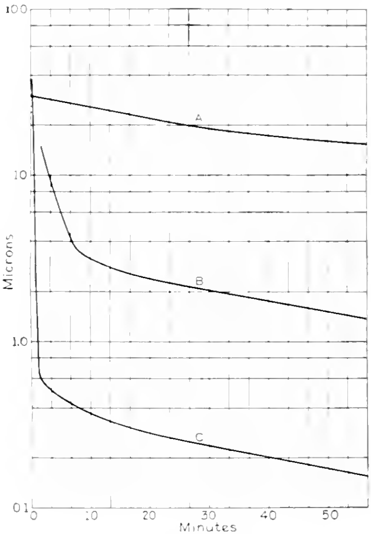

Fig. 74. Rate of Clean-up in Two-filament Kenotron
Curve *A*—No red phosphorous, no voltage on second filament
Curve *B*—No red phosphorous, 250 volts on second filament
Curve *C*—Red phosphorous on leeds of cathode filament, 250 volts on anode filament

shown in Fig. 71, the initial rate of clean-up is much greater in the presence of phosphorus. In the case of the lamp sealed off with air at 10 microns pressure, about 97 per cent of the gas disappeared in the first minute.

Fig. 73 shows the difference in the rate of clean-up of argon and air. In the case of argon (Curve *C*) the initial pressure was 6.5 microns, and in that of air (Curve *B*) the residual gas pressure was 4.5 microns. These

[14] The [illegible] is used as a convenient [illegible]

observations also show the effect of phosphorus in accelerating the clean-up.

In general, over 90 per cent of the residual gas is cleaned up in a lamp during the blue glow period, and the rate of clean-up during this time is much more rapid than that obtained subsequently. The final pressure attained on flashing varies from 0.01 to 0.001×10^{-3} mm. of mercury. During life the pressure continues to decrease very slowly, and even after the filament burns out, there is no increase in pressure.

Observations with different types of lamps have shown that there is no appreciable clean-up below 30 volts, but the rate of clean-up increases rapidly as the voltage is increased above this value, and is extremely rapid in case of 220-volt lamps.

Theory Regarding Action of Phosphorus in Improving Vacuum

Any theory regarding the action of the phosphorus in incandescent lamps must primarily take into account the phenomena observed in hot-cathode devices. Fig. 74 shows some results obtained with a two-filament kenotron (similar to that used in studying electrical clean-up effects without phosphorus) on the clean-up of residual air. Curve *A* serves as the blank to take into account any purely chemical clean-up, while Curves *B* and *C* show the effect of the presence of phosphorus. These observations show definitely that the phosphorus is most effective during the blue glow period, as has already been emphasized in describing the clean-up phenomena in lamps. The similarity between Curves *B* and *C* and those obtained in incandescent lamps also leads to the conclusion that the clean-up phenomena in the latter and in hot-cathode devices must be quite similar in origin, that is, the reactions probably involve the formation of ions as an essential intermediate stage.

The action of phosphorus in a lamp is undoubtedly not very simple. It may be partly chemical, as probably some P_2O_5 is formed in the presence of residual oxygen and this would assist materially in eliminating water vapor and hydrogen. In some experiments carried out by Messrs. Mackay and Huthsteiner, it was observed that very large amounts of hydrogen could be cleaned up by the action of phosphorus vapor in a lamp and that a black deposit was formed on the walls. This deposit was assumed to consist of solid compounds of hydrogen and phosphorus, although no conclusive evidence for this was obtained.

Phosphorus itself is a very interesting substance chemically. As is well known, it exists in at least two forms at ordinary temperatures—the white and the red. On heating the white to just below 247 deg. C., it is converted into the red modification. The latter has an extremely low vapor pressure even at 300 deg. C., while the white form is quite volatile. Again, on passing a discharge through the vapor of white phosphorus it is converted into the red modification which deposits as a fine yellow to red coloration on the walls of the glass bulb. This phenomenon has been investigated very fully by V. Kohlschutter and A. Trunkin.[15]

One theory of the action of phosphorus which has some foundation is that the phosphorus vapor at the moment of condensation on the glass removes positive ions from the gas in much the same manner as C. T. R. Wilson observed in the case of supersaturated water vapor. In the latter experiments it was found that on suddenly expanding a gas saturated with water vapor (so as to condense this vapor) there was a removal of ions on the surface of the extremely small drops of water.

The most recent and most interesting contribution to the elucidation of this problem is that published by N. Campbell.[16] He finds in agreement with other investigators that on passing a glow discharge through phosphorus vapor, it is converted into the red form, which deposits on the walls. Hydrogen, carbon monoxide, and nitrogen when mixed with phosphorus vapor clean up in the discharge very rapidly and in large amounts. An interesting observation (in accord with those made in this laboratory) is that "a lower final pressure can be reached with a given applied potential in the presence of phosphorus than in its absence." The explanation of this as given by Campbell is as follows:

"The absorption of gas ceases when the glow discharge ceases; and the glow discharge ceases when the falling glow potential becomes equal to the applied potential. The admixture of phosphorus vapor with the gas increases the pressure corresponding to any given partial pressure of the gas, and thus decreases the glow potential corresponding to that partial pressure. It therefore enables the discharge and the absorption of gas to continue when the partial pressure has fallen

[15] Zeits. f. Elektrochem, *20*, 110 (1914).

[16] Phil. Mag., *14*, 693 (1921). A short discussion of this subject has also been published by L. Hamburger, Proc. Amst. Acad. Sciences, *21*, 1062 (1919), whose observations are on the whole similar to those recorded above.

so low that, if the gas were present alone and its partial pressure were the total pressure, the potential applied could no longer be sufficient to maintain the discharge. When the partial pressure of the gas has fallen sufficiently, the phosphorus vapor, and not the gas, begins to disappear; and the disappearance of this vapor proceeds until the pressure of the phosphorus has fallen so low that the discharge can proceed no longer. And when the discharge ceases because the falling glow potential has become equal to the applied potential, it is not started again except by a very great increase of potential, owing to the wide difference between the falling and rising glow potentials in this vapor."

Furthermore, Campbell concludes that the reaction leading to the conversion of the phosphorus vapor into the red solid is reversible in presence of the discharge. The equilibrium is pushed towards the vapor phase when the red phosphorus on the walls is bombarded by positive ions, so that "as long as there is gas present in considerable quantity the conversion of white into red is never complete; there is always enough white phosphorus re-evaporating to maintain the discharge; and it is only when the gas has been greatly reduced in quantity that the equilibrium moves once more towards the solid phase, and a complete disappearance of all gaseous molecules is obtained."

This theory would account for the observation, often made in lamp practice, that clean-up effects can be made to occur in lamps in which red phosphorus is present on the bulb walls, instead of being on the leads or filament. The action in this case would be due to the bombardment of the red deposit by positive ions, with the resulting formation of a slight amount of vapor.

Regarding the chemical theory of the action of phosphorus, Campbell concludes that there is no evidence for any such theory and gives the following experimental observations to confirm this:

"(a) If the gas that has disappeared is restored, it is found to be in the same chemical state as it would have been if it has disappeared in the absence of phosphorus.

"(b) There is no simple relation between the quantity of gas that can be made to disappear and the quantity of phosphorus necessary for its disappearance. There is nothing approaching to a 'law of constant proportions.'

"(c) The amount of gas that will disappear depends very greatly on the surface condition of the walls of the discharge vessel."

As a working theory Campbell suggests that the red phosphorus covers the deposited gas and prevents it from being liberated again by bombardment. At the same time this red deposit provides a new surface on which gas can be absorbed. That the red phosphorus deposit adsorbs gas even in the absence of any discharge has been observed by the writer in a number of experiments.

From the point of view of this theory, it therefore is possible to account for the action of red phosphorus as used in lamp practice as follows: As well known the ordinary red phosphorus undoubtedly contains small traces of the white modification, as shown by the formation of P_2O_5 when it is exposed to air. Furthermore, when the glow discharge starts, some of the red phosphorus deposited on the walls becomes converted, as already stated, into the white form which volatilizes. This assists in maintaining the glow discharges at much lower residual gas pressures than is possible in the absence of phosphorus. The positive ions (or dissociation products according to Hughes) formed in the discharge are driven into the walls and immediately become covered with the red deposit. The gas pressure is therefore reduced very rapidly and finally reaches a value at which no glow discharge can occur with the given applied potential.

As mentioned by Dr. Whitney, arsenic, sulphur and iodine act in a similar manner to phosphorus in cleaning up gas in incandescent lamps. In fact any substance that can be readily sublimed acts in the same manner. It seems therefore that the most plausible theory would be that firstly the vapor formed by volatilization of these substances assists in maintaining a glow discharge at lower residual gas pressures, and secondly that the deposit formed by condensation of these vapors covers the gas driven into the walls (whether as positive ions or neutral dissociation products) and thus prevents it from being re-evolved readily.

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Condensers, Static

Excess Voltage Protection in Theory and Practice—II. Prehm, Wilhelm. (In German.)
Elek. Zeit., Apr. 21, 1921; v. 42, pp. 395-401.
(The first part of the author's investigation was published in *Elek. Zeit.* of 1914. Points out the disadvantages of the condenser as a protective device.)

Corona

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(Results of tests giving the effect upon the arc of heating the electrodes by means of small auxiliary reflectors.)

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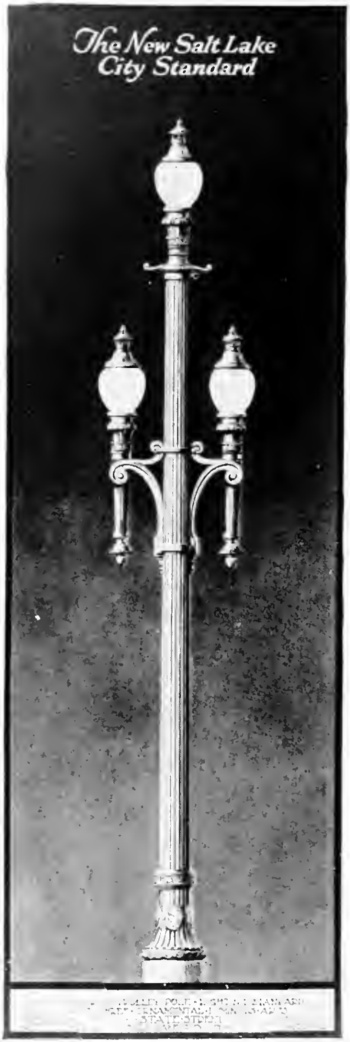
VOL. XXIV, No. 8

GENERAL ELECTRIC REVIEW

STREET LIGHTING ISSUE



Salt Lake City's New Lighting System

The Utah Power & Light Co. is now installing on State Street and Broadway handsome, large, three light standards, illustrated on this page.

This standard is conceded to be one of the largest and most handsome ever built for business district lighting. It was designed by W. D'a Ryan, Illuminating Engineering Laboratory, General Electric Co., Schenectady, N. Y., and manufactured by the Union Metal Manufacturing Co., Canton, Ohio.

Each pressed steel casing standard telescopes completely over a tubular steel trolley pole from which span wires are suspended. Lighting equipment consists of three ornamental, luminous arc lamps per standard.

This system represents the result of eighteen months' exhaustive study and experiment on the part of progressive Salt Lake City business interests, city officials and engineers of The Utah Power & Light Co. Their aim to obtain the finest business district lighting in the country has been realized both in the fine appearance of the new system and its superior illuminative value.

Union Metal and General Electric engineers will point out for you the "Right way for your White Way," whether your requirements be a large spectacular business district standard or a small, modest type for parkway or private grounds.

Union Metal Lamp Standards are distributed exclusively by the International General Electric Company in all foreign countries.

The Union Metal Manufacturing Co.
CANTON OHIO

UNION METAL LAMP STANDARDS

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

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CONTENTS

THE OLD AND THE NEW

On Broadway, Saratoga Springs, Fifteen 600 c.p. Pendant Type Fixtures Were Replaced by 70 Ornamental Standards, Each Having Two 1000 c.p. Units. At the same time all overhead wiring and unsightly poles were removed from the street

GENERAL ELECTRIC REVIEW

THE ART OF ILLUMINATING THE NIGHT

When the sun, that great illuminant, sinks below the horizon the opportunity of the lighting specialist begins. With all the splendor and beauty of daylight, perhaps more has been written about the beauty of the night than that of the day. We must tread carefully, skillfully, if we are to be worthy of the opportunity of adding to this beauty, of rendering it more attractive perhaps by contrast with our artificial illumination whilst fulfilling a practical necessity.

The coming of night marks a tremendous simplification of tonal values—a broadening of the panoramas and the scenes in our cities, in their silhouettes, street vistas, and their plazas. This is largely because of the absence of color, the limiting of the range of vision, and the partial illumination of the objects instead of their complete and entire revealment by the diffused light of day and because lighting is relatively speaking white light in its general every-day effect, in spite of the fact that there are many subtle differences from warm to cold hues in the various artificial lights employed.

In the panoramas of great cities seen from the heights, the effect is relatively uniform although to be sure when the lighting of the avenues and plazas are considered the variation in intensity and hue of the points of light forms an opportunity for fine variations and interesting effects.

In this connection it is interesting to recall the broad, splendid field of lighting of the Place de la Concorde as compared with the mall through St. James Park leading to the open place of Buckingham Palace. The lights lining the avenue are warm in tone and those surrounding the Palace and Place are of pale greenish hue. The incidental effect of lighting on the memorial which is of a warm purplish hue by contrast, in the center of the plaza, also is interesting.

History repeats itself in lighting as in other things. The brilliancy of our lighting, moreover, due to the modern use of electric current is fine, but until good design shall have triumphed over bad, both as to fixtures and as to quality of light, no real progress can be said to have been made.

Mere brightness in places will not properly replace good uniform lighting even if dull. There may be variations in the form and the intensity of lighting in the various parts of our cities, but it will be good only when this lighting is governed by a comprehensive scheme of arrangement. We are prone to be over proud of our achievements in modern times in the temporary and brilliant lighting of our expositions and fêtes. However, their chief claim to distinct and lasting value must always be that they have been well designed, for this feature of lighting though striking is not new. At times of fêtes, the lighting of the buildings, the garden walks, and the fountains at Versailles during the reign of the "Roi Soliel," as described by chroniclers of the period and illustrated in drawings, for sheer beauty and fineness of effect and arrangement would set us a hard pace with all our modern facilities. The difference of operation apparently is that an army of men must have been employed to manage these effects, which included even illumination under cover of the water in the fountain themselves.

The same may be said to be true of the interior lighting of the great palaces of France at the same period and of the palaces of Italy of the Renaissance where, in spite of the lack of electricity, most superb effects were achieved by the use of candelabra. Interior lighting, like that of outdoors, should be governed by considerations of design.

There is much talk about coöperation in this country and this is certainly very desirable if good results are to be obtained in the field of the industrial arts. It is perhaps more important that there should be a better understanding by technicians of the others' point of view and their difficulties, in order that the one in charge, whether he be responsible primarily for the practical end or for the aesthetic phases, may have a full understanding of the general situation surrounding a problem and work to harmonize the various factors in order that there may be fine results.

It is gratifying to know that so much attention is now being paid to the design of lamps both as to their power and appearance and to their placing. The writer believes that a study of the various able articles in this number will be of great profit to all who are interested in this subject.

Edward H. Bennett,
Consulting Architect to Chicago Plan Commission

Evolution in Street Lighting

By Dr Elihu Thomson
General Electric Company

Probably no one is better fitted than Elihu Thomson to narrate the history of street lighting because, among his early inventions of devices by which electricity could be generated on a commercial scale and applied to practical uses, his developments in street lighting equipment were instrumental in the rapid supplanting of oil and gas lamps by arc lamps. In his article, he first describes the conditions which existed during the successive periods when the fire brand, candle, oil lamp, and gas lamp were in turn the source of street "illumination," and then reviews the various features in the development of the modern electrical system.—Editor.

Before the introduction of arc lamps for street lighting, the illumination furnished was meagre indeed. When the moon was not shining, the long spaces between the low-power units were very dark and drear. The dark streets and ways gave little encouragement for stores to remain open. How different it is today, when these stores themselves contribute largely to the street illumination. Although the City of Paris in years prior to 1878 had employed gas lights more freely or more lavishly than most other cities, the illumination of the Avenue de l'Opéra there in that year by the now long obsolete form of arc light known as the "Jablochkoff Candle" showed that the effect obtained by electricity for streets and large spaces was so greatly superior that an impetus was given which led in a few years to a rapid expansion of the use of the open-carbon arc, not so much in the cities of Europe but to a far greater extent in our own centers of population.

The introduction of gas for lighting began a century ago, but even long past the middle of the nineteenth century it was generally supplemented in the outlying districts of cities by lamps burning some variety of oil, animal or vegetable, shielded from the wind by the well known lantern of window glass in metal framing. The gas lamps in general use were in similar lanterns mounted on poles and accessible as were the oil lamps to the lamplighter, who carried a short ladder and who turned on the gas and lighted it with the old fashioned, almost universal sulphur match. He began his rounds long before dark, a procedure which did not make for economy in gas consumption but which enabled him to cover his beat before night. The same was true of the oil lamps which were filled and trimmed in the daytime. It is within the writer's experience to see lamp posts climbed and the lanterns opened so that a light might be procured by a smoker who had forgotten to carry his brimstone matches.

Curiously, such a system survives even today and on a large scale, along the boulevards around Boston, where Welsbach-mantle naphtha lamps are still in use by the hundreds, each requiring the application, for a considerable interval of time, of a blow torch in the hands of the lamplighter, who, to complete his rounds at the slow pace, must begin lighting lamps at high noon so as to finish at twilight. The consequence is that such lamps may be seen burning late in the morning, to be relighted early in the afternoon. In these days of increasing price of hydrocarbon fuels, the impression is one of entire disregard of conservation of natural resources.

The actual candle-power of the gas lamps used for street lighting fifty years ago was low; a fishtail burner giving about 12 candles as a maximum was in almost universal use. The lamp posts were spaced at wide distances apart, from 150 to 300 ft. between them being very common even in our city streets, except perhaps in the most central section.

The introduction of petroleum oils between 1860 and 1870 displaced the burning oils that were before available for lamps. These were either animal or vegetable in origin exclusively. Camphene, or burning fluid so called, a mixture of about equal parts of grain alcohol and spirits of turpentine, was widely employed and pewter lamps fed with it were the usual means of illumination where gas pipes were not laid; but candles also were consumed in large numbers. Whale oil (sperm oil), palm oil, fish oil, colza oil, lard oil, and others were used in lamps. While the spermaceti candle was a high-grade candle, ranking with wax itself, the tallow dip at the lower end of the scale was very commonly found, especially in the country districts where home-made candles furnished a means of using surplus beef fat. The hard stearin candle was a result of the extraction of glycerine from the fats, and stearin or hardened fats have largely taken the place of other materials in candles. The demand for glycerine in the arts as produced by treatment of animal or vegetable fats or oils also stimulated the production of stearin.

Looking far back to the time before gas lighting had come into existence, a period of about a hundred years, we reach a time when street lamps were comparatively rare, entire reliance having had to be placed on the available animal and vegetable fats and oils. The centuries before and including the eighteenth century were not marked by brilliance of street illumination. Rather they might be aptly termed "dark ages," in a physical sense. The traveler at night wended his way through dark streets and alleys, and if prudent carried a lantern. The watchman of the early years is figured as one who was a lantern bearer. These were the days of the curfew bell, which had a very real significance in the life of the people.

And before that, in the dim past, the firebrand and the torch served the same purpose as they do even now in the wilder and sparsely settled regions of the world. In this connection, we may recall the period when the "link boy" had a function somewhat similar to that of the caddy in the modern golf game. He was employed as a torch bearer, the torch being called a "link," and lighted travelers on their way for a moderate stipend, offering his services wherever they were likely to be in demand. One can realize that street and road illumination was practically non-existent when such service was used in lighting the way for horses and carriages on the streets and roads.

While it is most interesting to trace from earliest times the development of artificial illumination and its relation to the culture and interests of past periods, there is no space here to do this except in the briefest and most general way. A book might easily be written dealing with the varied phases of the subject.

Coming now to the period of less than fifty years just past, which has seen more progress in street lighting than in the thousands of years which preceded it, it may be said that the invention and development of the dynamo-electric machine, now called an electric generator, rendered possible the application of electric energy on a large scale to the lighting of city streets and roads; for the fact must not be neglected that attempts had at times been made to sustain arc lamps by primary batteries in open space lighting, but at too heavy a cost. The Drummond lime-light, or calcium light of the old days, was sometimes used for special occasions.

Single arc lamps had also been employed for years previously in a few lighthouses. Reference has already been made to the lighting of the Avenue de l'Opéra in Paris in 1878 and subsequently. Lontin also had in operation there in 1878 at the Gare St. Lazare a series circuit of six or eight arc lamps. But it remained for the United States to show the real development on a large scale of city lighting by the carbon arc. The Brush series system, closely followed by the Thomson-Houston and other types from 1879, soon worked a revolution in this field, and the cities of America were not slow in recognizing the merits of the arc light for their streets and stores. The decade from 1880 to 1890 was characterized by the establishment of series arc lighting stations, mainly using the Brush and Thomson-Houston plant, on a grand scale, and the aspect of our city streets at night, from being embodiments of gloom, became bright and cheery. At first the open-carbon arc with a line current of about ten amperes was practically the standard, and dynamos capable of running 50 or 75 arcs on a single circuit became the usual equipment.

The Thomson-Houston arc dynamo possessed certain characteristics which rendered it especially suited to the operation of series circuits of many lamps. At the time, it was known to but few in the art that for sustaining what was called the long or open arc, the resistance of which fell with increase of current, the generator itself must possess stability characteristics whereby an increase of the current above normal was not followed by a voltage increase, even though the field coils were in series with the line, but rather that a fall of potential should ensue when the current tended to go beyond the normal value. This characteristic was absent in some of the early machines attempted to be employed for arc lighting, and consequently they could be used only with arcs whose electrodes were slightly separated, and with the lamp voltage so low as to require a current of about 20 amp. instead of 10, and the line drop with a given size of conductor was quadrupled. The Brush system, however, had the correct regulating characteristics and used the long or open arc. One feature of the Thomson-Houston arc system, which was of the greatest value, was its automatic regulation, maintaining the same current value on the line irrespective of the number of lights in use, from short circuit to full capacity. This feature also adapted the apparatus to be used with poor or irregular engine power. In those early days, the speed regulation of available engines was often very deficient. The regulator, demanding no attention, made up for the deficiency. The arc lamps of the Thomson-Houston system, as developed in the early days at the Lynn Works, were also characterized by the fact that the separation of the carbons at the arc was determined solely by the voltage across the arc, and was not dependent on the current value. This was indeed a valuable feature, for in case of a leaky line reducing the current passing through some of the lamps, the arc separation was maintained; while in those cases in which the separation of the carbons was dependent on the current value in the circuit, a leaky line was fatal to the uniformity or even regular operation of the lamps.

The Thomson-Houston dynamo was unique in embodying in its armature winding the first example of a three-phase winding of the "Y" type, whose terminals for direct current were connected to a commutator of only three well insulated segments. With the air blast mechanism to insert cold air at the slots in the commutator, a single commutator could operate 75 arc lamps in series, demanding a voltage across the commutator of nearly 4000 volts. At the Inventions Exhibition in London in 1885, where the Thomson-Houston plant was first operated abroad, the electricians of the time on seeing the dynamo connections declared: "It can't work, but it does."

Before 1890, the arc lamp expansion in street lighting became very great, and numerous large stations employing either the Brush or Thomson-Houston system were in operation in the large cities of the United States. The consumption of carbons in arc lamps was enormous, and their cost had been reduced to less than a quarter of the cost in the early years. Those were the days, too, when there was little restriction in the running of overhead wires, and one who remembers that time will recall the vast network over the roofs of buildings in cities of dead and live wires, for telegraph, telephone, fire alarm, and electric light service; now happily a thing of the past.

The first change from the early standards was the reduction, in Thomson-Houston practice, of the line current to 6.8 amp. and the corresponding increase in the number of lamps sustained by a given energy. The decade subsequent to 1890 brought other changes. The enclosed-arc lamp in many instances replaced the open arc, giving a longer life of the carbon electrodes without retrimming, owing to the restriction of air and lessened carbon waste, but this apparent gain was obtained at a considerable loss of efficiency of light production. Especially was this the case, as the writer pointed out at the time, in that form of enclosed-arc lamp in which the current supplied was alternating. The efficiency of light production fell so low that it was hardly equal to that of the better forms of carbon-filament incandescents. But the color of light was white; it was an arc lamp with similar characteristics, but a failure as a real light source.

The development of the flame arc, and metallic arcs, in which the light instead of being emitted as in the former carbon arcs, mainly from the highly heated surfaces of the carbon electrodes, came almost wholly from the arc flame itself (such flame containing light radiating particles and vapors) restored the arc lamp to its former position as the most efficient light source, and the long burning character given to the electrodes reduced to a minimum the attention required and the labor of retrimming. The rivalry between the incandescent lamp and the arc lamp has become naturally more keen since the former has been so greatly raised in efficiency by the use of the tungsten close-coiled filament in an atmosphere of inert gas; the gas-filled or half-watt lamp.

Will the incandescent type finally win out? To answer this we shall have to reckon with further arc developments and especially with possible improvements in electrodes for use in existing lamps.

The Principles of Street Lighting

By Dr. Louis Bell

Consulting Engineer, Boston, Mass.

In order to avoid confusion in setting forth the principles which govern the design and layout of street lighting systems, Dr. Bell first divides installations into three classes: the first, important streets where the public congregates and traffic is congested; the second, thoroughfares which are of secondary importance; and third, residential streets and highways where traffic is light and police protection less essential. For each of these he names the amount and other requirements of the illumination, describes the means of securing the desired effects, and points out the fundamental faults that have been characteristic of street lighting. Editor.

Street lighting had its origin more than two hundred and fifty years ago in the need of better precautions for public safety in large cities, Paris taking the initiative. Primarily it was and still remains a police measure. It is only within comparatively recent years that its function has been broadened into the lighting of streets as a matter of convenience for passers-by and of safety for those who drive along the streets.. The automobile, which implies fast and sometimes dense traffic at night, has brought with it new necessities, chiefly in the extension of street lighting along roads which previously required no light at all, since now the public scatters itself much more widely than it did twenty years ago. Broadly, street lighting separates itself into three somewhat distinct parts as modern practice has developed.

The first comprises the lighting of public places and chief streets, in which to the ordinary requirement of safety and convenience is added something on the score of display. In these cases more than necessity or convenience is taken into account, with a corresponding increase in the amount and often in the kind of light.

Second, comes what one may consider as normal street lighting, the illumination of thoroughfares carrying an important amount of traffic, and demanding also some special efforts in the way of police protection.

Finally, one has to deal with residential and other streets where the traffic at night is small and where police requirements are not severe. Such lighting ranges all the way from an intensity and distribution approximating that desirable for important streets to the mere marking of the way in suburban or even rural roads. Let us see now what these several classes of public lighting imply in the way of illuminants, and wherein street lighting practice has to differ from anything else in the art of illumination.

With respect to intensity, display lighting applied to public squares and chief streets requires something more than the mere ability to see one's way about. It implies the provision of illumination sufficiently good to enable the normal eye to see fairly well, to recognize persons easily, to read addresses with facility, and to get about without any conscious effort at seeing. To accomplish this end the intensity of illumination must be pushed much farther than has in the past been common practice. In the earlier days of street lighting it was usual to put an arc light at each street intersection, be the distances more or less. When the blocks were short, not over a couple of hundred feet, and the arcs were of the highest power in commercial use the result was quite good; but where the blocks spanned out to 200 yards or more and petty economy indulged in the use of "half arcs" the result was exceedingly bad.

Even with the spacing and illuminants first mentioned the intensity averaged rather low, considerably too low midway between lamps, since the earlier arcs throw their maximum light at a distance from the base of the pole little greater than its height. With the introduction of the magnetite arc, in which the arc stream itself is the source of light and the maximum intensity is thrown near the horizontal, a great deal more even and satisfactory illumination was obtainable; but the temptation has always been toward spanning out the arcs too widely.

To serve the purpose of the highest grade of illumination here described, the eye must receive enough light to get beyond the stage of "twilight vision" which merely enables the eye to discriminate light and dark masses or very coarse details. In practice the plane of illumination should be carried somewhat near 1/10 foot-candle, ranging perhaps from half this amount at the darkest spots to at least double near the lamps. In fact the most important streets and public places ought to have an average of a good quarter of a foot-candle, giving light enough to read addresses or consult a notebook. Such is the lighting which ought to be furnished in places out-of-doors where the public gathers at night, and in streets where the nocturnal traffic is dense or the requirements for policing exceptionally severe.

It is easy enough to get this required amount of light in divers ways. It could actually be furnished by comparatively small incandescent lamps closely placed. One can in this way carry the nominal plane of illumination up to the required point, but the effect is rather singular and not altogether satisfactory. The writer remembers seeing a striking example of fairly high illumination derived from small sources in Buda-Pest some years ago, where the gas works paid a certain percentage of their gas as a species of franchise tax and the City overworked this arrangement by spacing Welsbach burners at 40 or 50 ft. over a surprisingly large extent of the important streets and some of the unimportant ones. The actual light in the streets was exceptionally great, but the small units closely spaced failed utterly to give an effect of high illumination although their number was most impressive.

One perhaps can get an idea of the reason by thinking of a main street as a great corridor with a dark ceiling of the night sky, moderately bright walls composed of the facades of buildings, and a fairly light floor. In order to obtain the maximum usefulness from light sources located in such surroundings it is clear that, while most of the light should be cut off from a vain attempt to illuminate the sky, brilliancy of result requires a liberal lighting of the sides of the corridor, as well as efficient illumination of its floor for the sake of diminishing the risks of traffic. In other words in a situation of this kind, and in a public square as well, light thrown laterally is far from wasted. Small sources placed low with the necessary reflectors over them to keep light from being wasted skywards do not satisfactorily illuminate the facades of buildings, however effective they may be on the street.

It is in places of such sort that powerful arcs placed fairly high and spaced at a distance not over four or five times their height are particularly effective. Large incandescent lamps if treated in a similar way produce much the same effect, save for a difference in color which is more or less a matter of taste. But the arc in this kind of illumination finds its strongest claim for the survival of the fittest. Pushed to the limit one gets the white-way lighting, which in its early days was much abused but now has come to a better sense of proportionate values. The low posts used in some of the earlier installations of this kind were simply a concession to a petty and pound-foolish economy. The lamps should be carried to a height of 18 to 20 ft. or even more. Ornamental units do a singularly good job in this particular kind of intensive lighting.

The great bulk of street lighting however falls into another category. The intensity required is determined by convenience in getting about with moderate traffic. The streets are mainly lined with residences rather than shops or public buildings, are often bordered with trees, and in no way demand high intensities. Not far below the intensities just noted as proper for chief streets, one falls into a region where vision fails of detail while fully retaining power to see obstacles, note moving objects, at least as silhouettes, keep track of the curbings, and in general see the surroundings as a whole while without being able to distinguish minutiae unless immediately under the lights. The illumination must be sufficient in a general way for policing the street properly, enough to enable an officer to see predatory prowlers in places where they have no excuse for being. The situation does not require close discrimination of any kind.

The general plane of illumination should be comparable with that of bright moonlight, ranging say from 1/20 foot-candle down to a half or a third this amount. Full moonlight in our latitude is somewhere around 1/50 of a foot-candle, but has the advantage of being extremely well spread over the area to be lighted, thereby presenting no dark intervals between light sources. The main practical difficulty in this class of work is not in getting enough light, which can readily be obtained from incandescent lamps, but in getting the light where it will do the most good. Trees are here a constant difficulty, but it is a field where the larger incandescent lamps, 100 to 500 watts, find particular usefulness.

As the sides of the corridor in this case are usually relatively dark, there is no particular advantage to be gained in attempting to illuminate them, save at a comparatively low level in order that the householder may see his own door steps. It is therefore permissible to bring the lights considerably lower, to cut off the light above quite completely, and to use units hung merely as high as trees permit. Fixtures and glassware adapted to throw the light up and down the streets rather than laterally often find a useful place in this more general phase of street lighting.

Beware, however, of trying to economize by spacing lamps too widely, because where trees line a street the shadow effects get progressively worse as the sources are spanned out and it becomes necessary to keep this feature in mind in planning the size as well as the spacing of lamps.

Finally one comes to the minimum stage of lighting which is of no inconsiderable value although the intensities required may be very slight as a mere matter of photometry. The spaces now to be dealt with are outlying streets, perhaps stretching far into the country or becoming thoroughfares between towns. Automobiles carry their own lights with them, but these are rarely powerful enough to permit close discrimination of objects on the road when the car is fast driven. A few states have made definite efforts to compel the carrying of headlights capable of proper illumination of the roadway without interfering by their glare with the vision of other drivers. But there is no doubt whatever that a road properly marked even by small lamps is a great deal safer for traffic than one marked not at all. Anybody who has ever been caught out in a car at night with the lighting system gone bad realizes how much an occasional lamp is an aid in this time of trouble.

This kind of illumination is the special place for the smaller incandescent lamps, from 40 to 100 watts, and their spacing should be not in accordance with a set specification but should be adjusted to the needs of the road. It is futile to attempt to set a particular amount of illumination suitable for this task even in the immediate outskirts of a city. It may approximate ordinary street lighting, but in the long run it is quite out of the question to furnish enough energy for this liberal kind of treatment, while it is entirely feasible to place lamps so that by following them one can always keep safely within the roadway. Hence on curves it is good judgment to space the lamps with this requirement in mind, while on tangents the distances may be largely increased.

There are many miles of very decently lighted country roads where the principles here set forth have been borne in mind. The common tendency however is toward a spacing of lamps on every fourth or fifth pole irrespective of the character of the road, perfectly good lighting to be sure but less economical and efficient than if the spacing were varied to accord with the situation. In this scattered lighting, too, there is advantage in using fixtures that throw the light along the road rather than laterally, but the gain is less than in the lighting of more important streets since the small lamp is really rather a marker than an illuminant and the corridor to which it corresponds has the blackness of night on the sides and ceiling, and very commonly the blackness of asphalt as its floor.

Panel Illustrating an Early Type of Street Lighting, reproduced from "The Lights of Paris," by Isabel Smithson, published about 35 years ago

Intensive or Super White-way Lighting

By W. D'Arcy Ryan

Director, Illuminating Engineering Laboratory, General Electric Company

Although the first installation of intensive or super white-way street lighting was made less than five years ago, the system has proved itself so attractive from the architectural, business-building, and protective standpoints that it has already been adopted by a number of other cities and the idea is spreading rapidly. Mr. W. D'A. Ryan, who has always been an ardent advocate of better lighted streets, presents in this article salient information as to the super white-way system and summarizes briefly the facts concerning the installations to date.—Editor.

Ornamental electric lighting on business streets had its inception in 1906 on Broadway, Los Angeles, in the form of a cluster globe system. The illumination from these original carbon lamps differed greatly both in intensity and quality from our modern conception of a white-way. Similar systems were installed at St. Paul, Minneapolis, and many other cities. During the next ten years remarkable progress was made and the white-way idea spread to practically every city and town of importance in the country. Cluster standards were largely superseded by single units using high-power incandescent and luminous arc lamps. The most notable of these installations was at New Haven, Conn., in 1910, when for the first time the luminous arc was used in its ornamental form.

October, 1916, marks the inauguration of a new epoch in street lighting, the intensive or super white-way. The Exposition in 1915 stimulated an interest in "Light" that bore fruit first in the intensive illumination of Market Street and then finally spread to include the entire retail business section of San Francisco.

The purpose of this article is to define briefly what constitutes an intensive white-way and to report the status of the movement to date.

Such lighting is made possible by standards eighteen or more feet in height, carrying two, three, or more high-power luminous arc or incandescent fixtures. It differs from the ordinary white-way lighting in the following respect: greatly increased illumination, relatively high lamp standards, initial installation costs ranging from $4.00 to $8.00 per foot frontage in place of approximately $1.00 to $2.00; and maintenance costs proportionately higher.

Intensive white-way lighting might be regarded as general floodlighting; advantage being taken of the natural decorative feature of the unit itself as contrasted against ordinary floodlighting where the light is concealed in a uni-directional floodlight housing. For the most part the expense of installation and operation of such systems is borne by the property owners and merchants directly benefited. The especially prominent features of this type of lighting are:

(1) The cosmopolitan atmosphere and dignified aesthetic effects of the standards by day as well as by night.

(2) The minimized window reflections on account of the height of the lamps.

(3) The intensity of the illumination and the uniformity of distribution on the street and building facades, with emphasis on the corners in both the light and the design of the standards.

(4) The readiness with which features of people in the street can be distinguished, particularly in automobiles with the tops up.

(5) The illumination of the building facades and sharpness of the cornice lines against the sky.

(6) The increased intensity as compared with the lighting of intersecting streets, clearly marking the main thoroughfare.

Powerful light sources giving a live white light at a good operating economy are required for such intensive lighting. The 6.6-amp. luminous arc and the 1000, 1500, and 2500-c.p. Mazda lamps are commercially available for this purpose. While most of the initial installations have been with the luminous arc, the latest intensive system was made in Saratoga Springs with Mazda lamps. Experiments are now being conducted to perfect glassware which when used with the incandescent lamp will tend to impart to the source a certain desirable lively sparkle that heretofore could be obtained only with the arc.

Statistics on the intensive or super white-ways that have been installed up to date are given in the following. At first glance one may be impressed with the relatively high installation and maintenance costs and the scheme as a whole might be thought of as "extravagant." It should be remembered however that nothing is extravagant that is profitable, and the benefits and advantages, financial and otherwise, of the intensive or super white-way have been demonstrated beyond contention.

Market Street, San Francisco

This system consisting of 137 trolley pole standards, each carrying three 6.6-amp. ornamental luminous arc lamps, was lighted Oct. 1, 1916. The standards are 32 ft. overall and are placed opposite at approximately 110-ft. intervals. The system cost about $100,000, and was paid for and installed by the Pacific Gas and Electric Co. The trolley poles and ornamental bases are the property of the United Railways, which also contribute to the Downtown Association fund for the maintenance of the two side lights which are burned until midnight. The center lamp operates all night at the City's expense. The total operating cost per year is $43,963.

Triangle Lighting, San Francisco

All other retail business streets of San Francisco's downtown district were intensely lighted January 1, 1919, by 25-ft. two-light luminous-arc standards, located in a staggered arrangement with one standard to each 65 ft. of street. This installation cost approximately $85,000 and is the property of the Pacific Gas and Electric Co. One hundred and ten lamps are burned all night and are paid for by the City. One hundred and sixty-eight midnight lamps are maintained by the property owners and merchants through the Downtown Association.

Fig. 1. Broadway, Los Angeles, Cal., Intensively Lighted by 6.6-amp. Luminous Arc Lamps

Main Street, Salt Lake City

Although the original work on intensive lighting was done on Market Street, San Francisco, the first installation to be officially lighted was on Main Street, Salt Lake

Fig. [illegible] State Street Looking South, Chicago, Ill. Lighted by Novalux Stippled Glass Globe Units Containing 1000-watt Multiple Mazda C Lamps

Market Street, San Fran[illegible] C[illegible] C[illegible] Inaugurating th[illegible] P[illegible] of G[illegible] Lighting

Fig. 4 Illustration of Lighting Effect on Randolph Street, Chicago, Ill., by Ornamental Luminous Arc Lamps

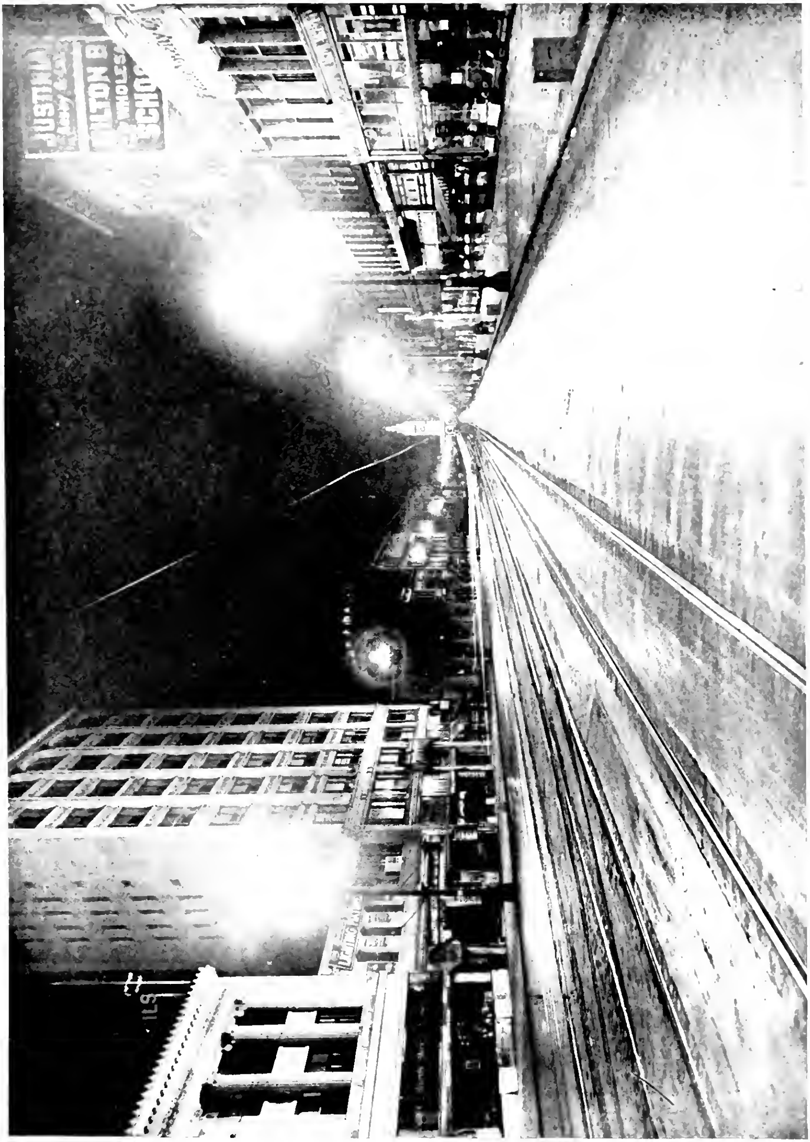

Fig. 5 Market Street, Looking Toward Ferry Building, San Francisco, Cal., Lighted by 6.6 amp. Ornamental Luminous Arc Lamps

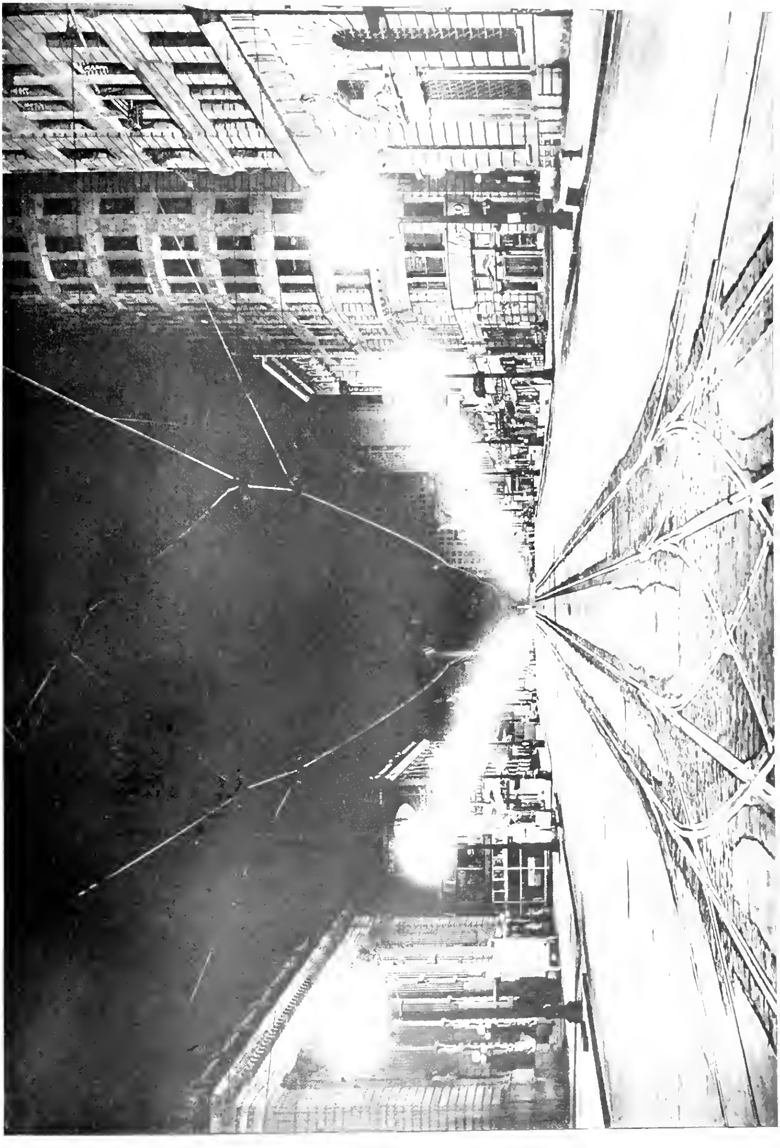

Fig. 6. Main Street Looking North, Salt Lake City, Utah, Lighted by 6.6 amp. Ornamental Luminous Arc Lamp

City, on September 30, 1916. It consists of 70 three-light luminous arc lamp standards. The standards are 29 ft. overall and are spaced opposite at 100-ft. intervals. The cost exclusive of the substation equipment, which is the property of the Utah Power and Light Co., was about $32,000 and was borne for the most part by the property owners. The operation cost is approximately $13,000 per year.

Fig. 7. Main Street, Salt Lake City, Utah, Lighted by Ornamental Luminous Arc Lamps

State Street and Broadway, Salt Lake City

The new street lighting on State Street and Broadway will be virtually an extension of the Main Street system. There will be 336 6.6-amp. ornamental luminous arc lamps used. The standard will envelop the present trolley pole and carry two lamps below and one above the trolley wire. The total cost of this new installation will be approximately $100,000. The Utah Power and Light Co. will pay for the substation equipment and the feeders to the street circuits. With the exception of a small amount contributed by the City, the remainder of the installation expense and the yearly maintenance will be borne by the property owners.

Broadway, Los Angeles

This installation consisting of 134 two-light 6.6-amp. luminous arc standards, 27 ft. in height, was lighted January 17, 1920. Sixty-seven lamps burn all night and two hundred and one are extinguished at midnight. The average spacing is 106 ft. and opposite. A total installation cost of $85,000 and a yearly maintenance of $13,700 are assessed against abutting property. The Bureau of Electricity of the City of Los Angeles supplies power and maintains the system.

South State Street, Chicago

The lighting on South State Street, Chicago, is representative of the comparatively successful results which may be secured at a

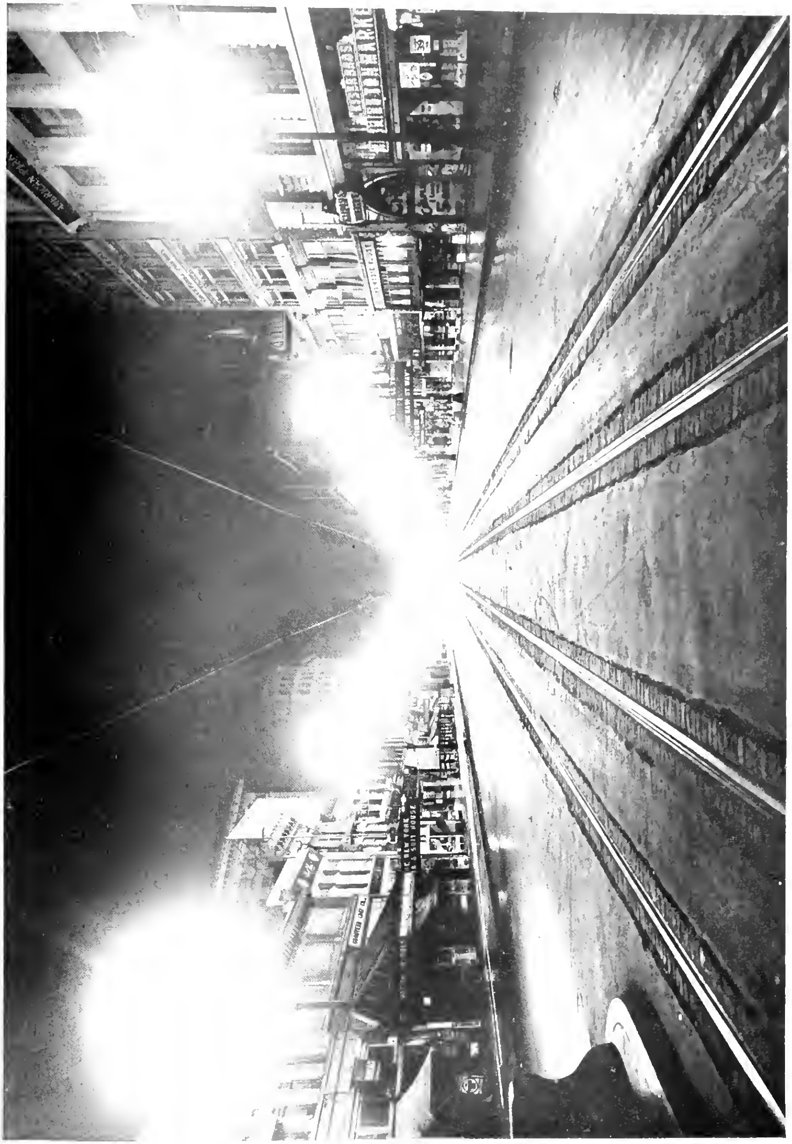

Fig 8 Market Street, Looking Toward Twin Peaks, San Francisco, Cal., Lighted by 6.6 amp. Ornamental Luminous Arc Lamps

relatively small installation expense. One-thousand-watt multiple lamps (approx. 1900 c.p.) in trolley pole bracket fixtures are located 100 ft. apart on each side of the street. Artistically, a complete design of standard and fixture equipment, as in the preceding examples, is of course much to be preferred.

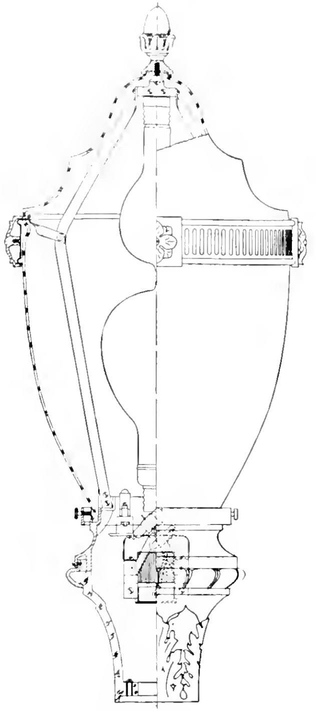

Fig. 9. Part Sectional Drawing of the Duoflux Lighting Unit Used in the Lighting Installation at Saratoga, N. Y.

Broadway, Saratoga Springs, N. Y.

This system was lighted June 19, 1920. Nearly a mile of street is illuminated by 70 standards. Each standard has two Duoflux units and each unit contains one 1000-c.p. and one 250-c.p. series Mazda lamp. Besides being of a new and exceptionally pleasing design, this fixture possesses a distinctive utilitarian feature. The large lamp in each globe is extinguished at midnight and the smaller one is lighted. This arrangement permits the use of reduced illumination after

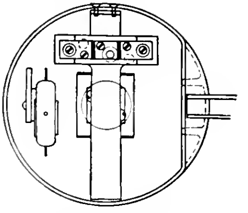

Fig. 10. Sectional Plan Through the Casing of the Unit Shown in Fig. 9

midnight, without a duplication of lighting circuits. The Saratoga installation cost about $32,000 and was installed and is owned by the Adirondack Electric Power Corporation. The city pays the entire maintenance cost of $10,500 yearly.

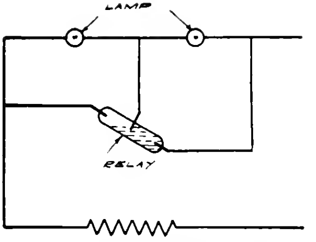

Fig. 11. Wiring Diagram of the Duoflux Unit Shown in Fig. 9

Randolph Street, Chicago

In accordance with proposed plans, the present trolley poles on Randolph Street will be utilized as lighting standards. There are to be two 6.6-amp. luminous arcs on each standard. Eventually it is proposed to extend this system throughout the Loop District.

Architectural Aspects of Street Lighting

By J. Woodley Gosling
Illuminating Engineering Laboratory, General Electric Company

This article possesses the distinction of being one that links the work of the decorative designer with that of the engineer. In doing so, it treats of the architectural principles which should be employed for the design of strictly utilitarian lighting equipment to harmonize with the environment of its location. The accompanying illustrations show some of the ornamental lighting standards that have been developed. In viewing the night photographs of installations, it should be borne in mind that the required exposures were so long as to record only those objects which were stationary. The imagination must be brought into play to place the actors on the "stage." Strolling window shoppers, crowds on their way to the movies, streams of busy pedestrians bent on their many errands, bustling jitneys, clanging trolley cars, and a steady stream of pleasure cars must move through the street or it will be a dead thing with no use for light.—Editor.

The consideration of the relation of architecture to the illumination of streets has undoubtedly been slighted by those responsible for the installation of the lighting systems installed in some of our cities. The street may well be considered as a unit to be studied and developed the same as each of the buildings which face it and taken together make up its character. Very decided factors in the forming of the character of the street are the methods and means of lighting employed. All municipalities must maintain some sort of lighting system and each has to meet its severely practical needs before considering the aesthetic. When the engineering requirements are met by an architectural treatment of the visible parts of the system in such manner that they do not mar but add to whatever existing excellence the thoroughfare may possess, the accomplishment is something more than merely fulfilling a civic necessity; it is a definite gain toward the creation of the city beautiful.

Every municipality contains a certain element which has in mind the beautifying of its streets, parks and buildings, and many have crystallized this desire on the part of its citizens into organizations for civic improvement and into various forms of commissions for city planning or societies and boards for the control of municipal art. A few have made definite strides toward the aesthetic consideration of our subject and have viewed it with the eyes of experienced architects.

After many conferences with leading architects on the subject of the decorative design of street lighting apparatus, in efforts to solve definite problems, it apparently develops that we have a condition in the decorative treatment of streets wherein the lighting standards play an important role, which must be fulfilled by applying the principles of design and proportion without the customary reference to precedent so generally imperative in the creation of things having a decided architectural aspect.

The extremely high intensity of present day street illuminants, which has come with such rapid development, is responsible for this condition. In the last hundred years countless lamp posts have been made and most of them have been placed on our streets with utter disregard to their general effect on the appearance of the streets as a whole. Before the days of general lighting of our streets with gas there was no great difficulty experienced with the problem. An occasional bracket on a building, a lamp hung over a street by cords or wires, or ornamental standards either singly or in groups near important structures, were all that had to be considered.

Ten or fifteen years ago it was necessary to place a great many posts on the street to obtain what was called a White Way, and those posts were generally crowned with a collection of round glass globes which gave a woefully cluttered effect although it is not to be doubted that some of these same cluster units look very well when used in suitable places. When the old gas posts were utilized for electricity they carried lamps of such low intensity that their number could not very well be reduced, but these were small and seldom close enough together to give much annoyance. Furthermore, they were not placed with any idea of illuminating the street as we think of it today, but were mere markers indicating the curb lines and when compared with present day street lighting were little more than guides, like lighthouses along the coast.

The posts may still be kept far apart but they must be taller and of greater bulk to meet several of the following conditions:

(1) There is something in the high intensity and great brilliance of illuminants of recent development for exterior lighting, in both the incandescent and luminous arc types, which suggests a bold and outstanding treatment of the decorative device that is to house or carry the lamps. A new element has injected itself into the field of study for the architect which cannot be represented on the plane of a drawing or portrayed in color. There is no paint bright enough to represent

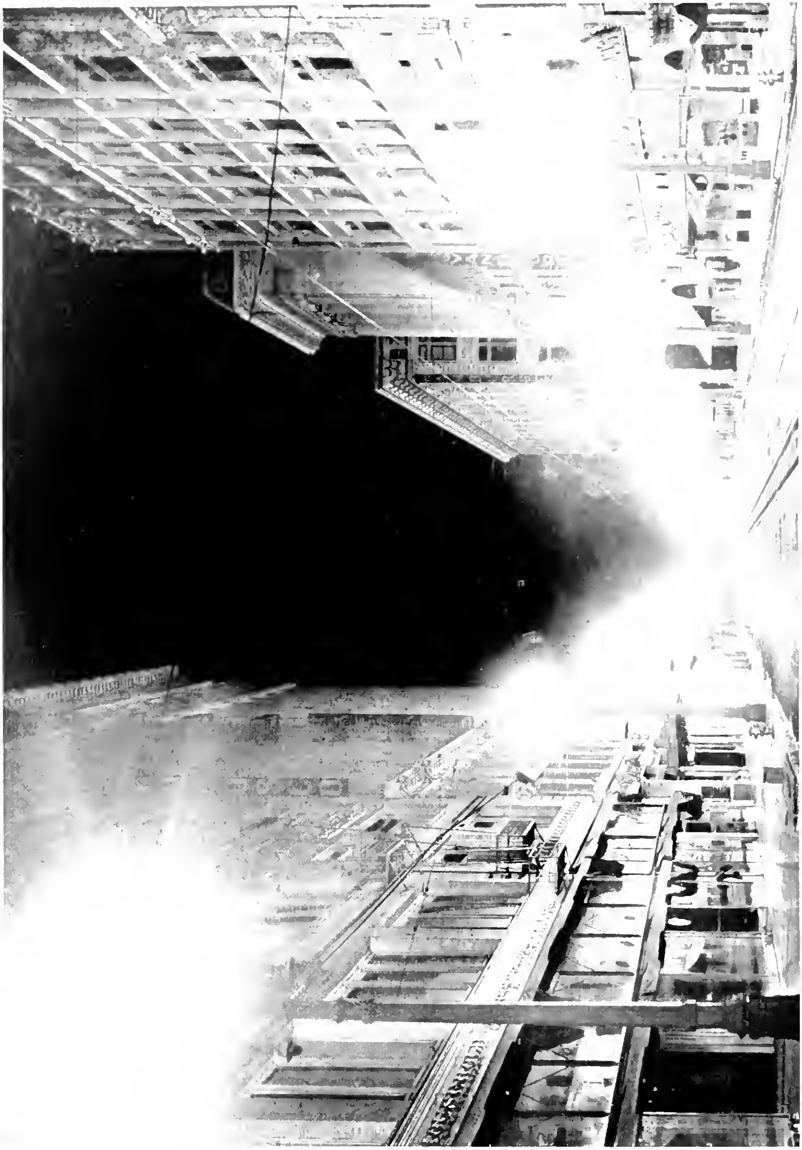

Fig. 1. Broadway, Los Angeles, Cal., Looking South from Between Seventh and Eighth Streets

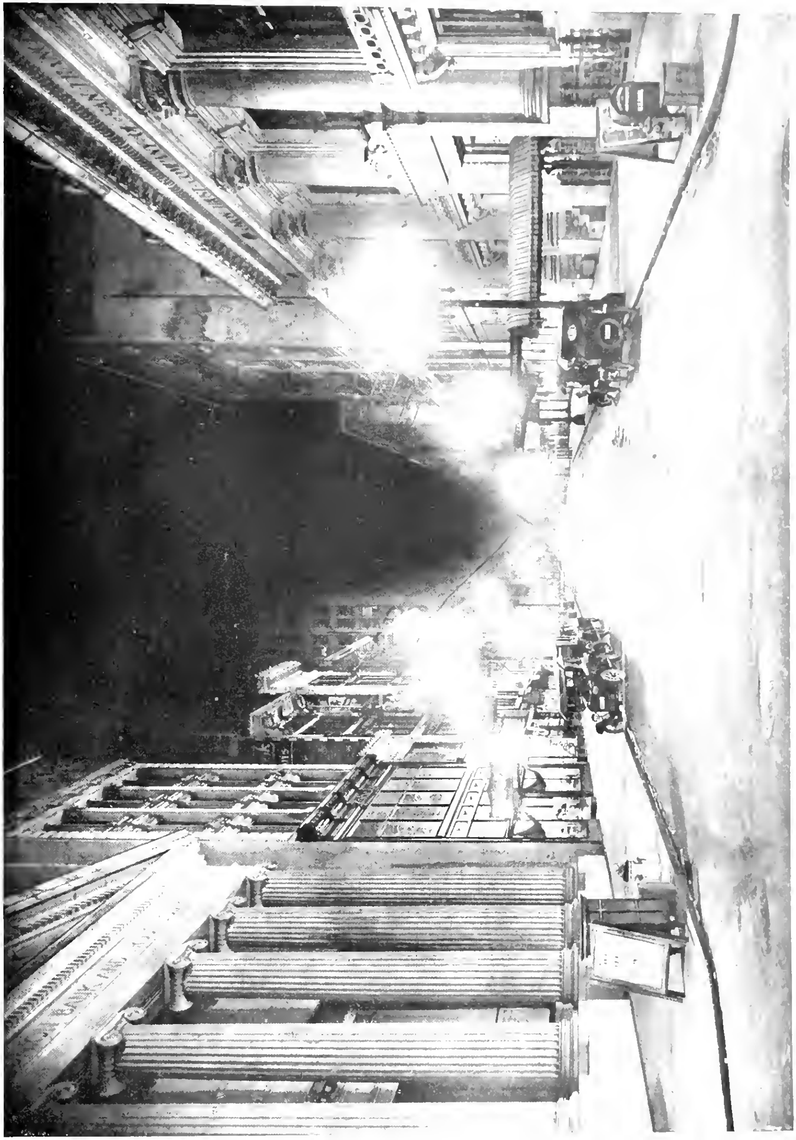

Fig. 2 Grant Avenue, Looking North, San Francisco, Cal. Intensively Lighted by 6.6 amp Ornamental Luminous Arc Lamps

its light and none deep enough to portray its depth of shadow. As a simple example of the necessity for large dimensions in the housing for the new illuminants, just recall that the filament in a carbon lamp of say 16 c.p. could be looked at without any great inconvenience or eye strain, and when a six-inch globe was placed over the bulb the light was so diffused that the source appeared as a pleasantly glowing sphere. Lamps up to 2500 c.p. (approximately 150 times the volume of light) are now used; and if such a bright object should be viewed for any length of time the retina of the eye will be so closed that nothing else will be seen until it readjusts itself to objects of low intensity. In order to make this bright source of practical use for street illumination, it has been encased in a globe or lantern of translucent glass of such size that it can be looked at without experiencing uncomfortable sensations. It does not have to be 150 times the size of the little old six-inch ball because that was not the limit of eye endurance. By a long series of tests it has been found that for general work a 600 to 1000-c.p. lamp will require a globe about 17 in. in diameter and 18 to 20 in. high. This sets roughly an example upon which to gauge the bulk, size or magnitude of the lighting standard, to which of course must be added the other considerations of practical necessity, as:

(2) The height must be great enough to give good general distribution of the light, which may be controlled by the location of the lamp in the globe, by the type of glassware, form of globe, reflectors, refractors, or type of lamp itself. It must be high enough to give the necessarily increased size of the lighting unit an appearance of grace and symmetrical proportions in relation to its support. Considerable study has been given to the treatment of glassware and due effort been used to obtain graceful forms and practical dimensions to meet the requirements of the illuminants of different sizes. By that is meant the designing of large globes to be used with such high-intensity lamps as the 600 to 1500-c.p. types and of smaller ones to accommodate lamps of less brilliance, the intention being to have available good looking glassware which meets the requirements of the engineer and the city planner for any problem which might arise.

(3) The base of the standard must be of large enough diameter to give good individual decorative appearance and accommodate the required installation of transformer, cutout or other protective devices.

(4) The shaft must be of such diameter that when the unit is atop, in the case of the vertical arc, an ample insulating gap will be assured, and

(5) Of such bulk of base or even of shaft as to meet special requirements, such as the encasing of trolley poles for lighting standards or meeting the requirements of traffic or local engineering needs.

When the artist in Pompeii designed a standard to carry a little oil lamp, or when Grosso conceived the lanterns and torch brackets which are on the walls of the Pallazo Strozzi, there were no engineering problems to be met other than that they must each make a practical thing, and they made them beautiful. The principle governing the making of the practical device which is a beautiful thing to look upon has not changed one jot, but the application and use has become somewhat complicated due to modern engineering needs. The introduction of engineering principles into the art need not preclude the making of beautiful standards or lanterns any more than the definite knowledge of the strength of materials need produce architecture which is not beautiful.

The statement that there is "something in the intensity and great brilliance of the modern illuminant" seems to be the salient point to be considered in the selection and control of the form and size of the decorative device which is to house or carry the illuminant. The design of a decorative thing of utility is not good design unless the utilitarian is considered first. Then must be considered the sternly practical necessities of such things as are mentioned under the preceding headings.

The standard or other lighting unit, after meeting the essentials of engineering needs, must fit its place and here enters a host of questions which will concern the designer, engineer, city planner, or architect.

Certain principles of composition and design must govern both the unit and its proportion in the street but there is no precedent in ancient art wherein we must meet a condition which requires the placing of a series of posts or poles all alike at stated intervals. The very definite and nice arrangement of the columns of the Parthenon are there by a principle of proportion which cannot be applied to an indefinite line of columns carrying lights on a street, but we can at least consider such points as individual

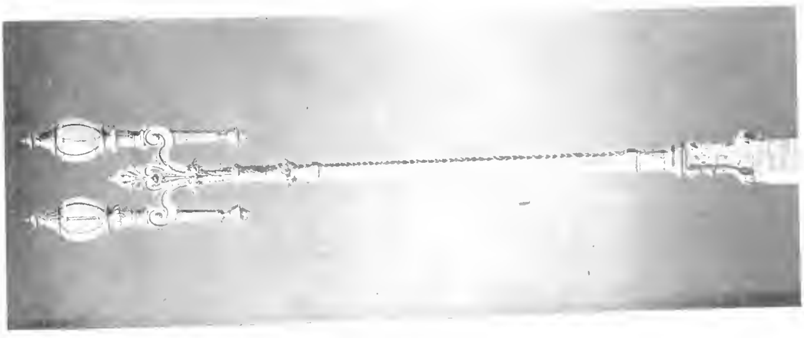

Fig. 3. Ornamental Standard in Use on Broadway, Los Angeles, Cal

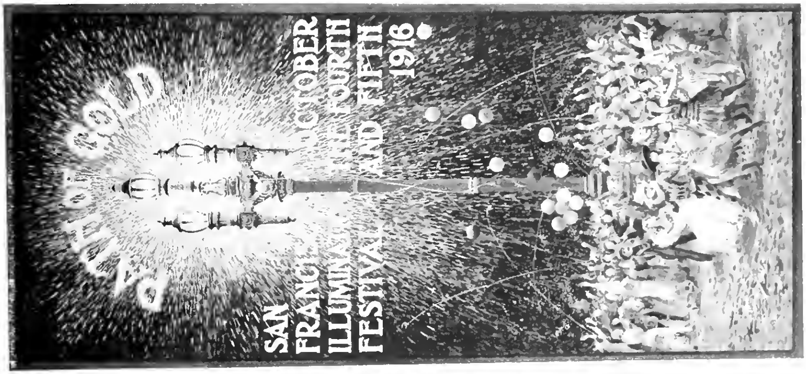

Fig. 4. A Poster Designed at the Time of the Inauguration of the Market Street System, San Francisco, Cal

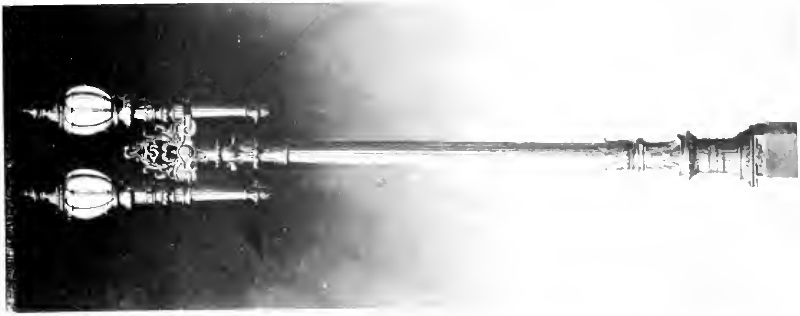

Fig. 5. The Standard in Use in the "B[illegible] Triangle," San Francisco, C[illegible]

grace of silhouette, color, decorative detail, suitability of glassware, the effect on the street with relation to buildings, planting, type of street or necessary kind of lighting.

The criticism continually made by architects of the trend of recent design in lighting standards is that "they are out of scale" or that "they dwarf everything nearby." When the scale of present day lighting apparatus is gauged by that of the Fifteenth Century perhaps they are somewhat large and insistent, but modern conditions must be met in this field as well as in that of architecture where buildings are surely mounting skyward in business districts particularly. There is a practical danger in placing a lighting unit of such intensity as 1000 to 1500 c.p. down anywhere near the level of the eye, and to keep it up where it is safe electrically and where such brilliance will have proper diffusion and not endanger the eye means the designing of shafts, poles or supports of such size or bulk as will be commensurate with the practical and so blended with the architecture of the street as to be as inconspicuous as may be.

Particularly efficient refractors have been developed which may be used to offset the necessity of extreme height and size of poles. A study of this glassware by architects or city planners who contemplate the lighting of bridges, wide open areas, or boulevards will materially assist them in the solution of such problems.

The design of the standard may be of extreme simplicity of contour as befits a small urban residential district, or it may be a thing of monumental character to grace the civic centre of a prosperous city. Where a great many standards are to be used in a given district it is advisable to select a design which is very simple. The continuous repetition of an ornate thing becomes monotonous. If a single street is to be illuminated, which is more often the case, greater freedom may be used in the selection of a design bearing surface decoration. The silhouette in any case must be simple and graceful. Simplicity of contour will insure an appearance of neatness on the street as well as tend toward an easier blending with the great variety of the architectural styles of the buildings fronting our streets.

It may seem contradictory to demand greater size and at the same time ask for inconspicuousness but this may be accomplished by the possibility of longer spacing, decorative treatment which is in fair accord with the street architecture, and the use of color on the standards or posts and glassware—to use a term coined at the time of the construction of the Exposition in San Francisco, "Paint them out." In the congested districts of many of our cities the effect is very oppressive to see streets cluttered with a heterogeneous mass of trolley poles, signs, vehicles, and lighting standards, all of a shroudlike tone. Black is all right when used in moderation with some colors. It does nicely for some kinds of leather and for printers' ink, but some tint or shade of green, buff, or brown on such things as lighting standards and poles on the street will give a much happier effect. It is not always necessary to go to the expense of painting lighting standards in imitation of bronze, although that is generally effective and is better than the hue of the inside of a coal chute. Every time a pole is painted black some of the light is wasted. Black will absorb all the light which strikes it while colors will reflect at least some of it.

Complaints have been made that dust will show on ornamental forms. Dust will show more on black and dark tones than it will on colors which tend to grays and gray-greens and these colors will be far less conspicuous, by day at least, and tend to make the standards and trolley poles less insistent in the general makeup of the street.

Lighting Standards Having a Monumental Character

Fig. 1 is of Broadway, Los Angeles, California, and shows the effect on a business street of an up-to-date installation which is the result of careful and well coördinated effort by the property owners. The street is 100 ft. wide from building to building with the structures of a generally even height. All are very light in color, being soft gray, cream, white, or buff. The lighting system is of luminous arcs, two to a pole, with underground wiring.

The standards are designed in a style which suggests the Spanish Renaissance and, although far too ornate for the average city, are in keeping with the spirit of Southern California. The light source of each is about 25 ft. high and is so placed that there is excellent general illumination throughout the length of the street. The sparkle and life of the light in this avenue are particularly cheerful and when seen from the distance and height of Mt. Lowe at night its radiance is remarkable. Fig. 3 shows the details of one of the standards in use, the other being of

Fig. 6. Lighting Standard Installed on Broadway, Saratoga. Two Duoflux Units

Fig. 7. Lighting Standard Installed in Congress Park, Saratoga. Single Lamp Unit

Fig. 8. Design of Proposed Standard for Augusta, Ga.

similar silhouette although different in ornamental detail.

Other important California lighting installations are on Market Street and the Business Triangle of San Francisco, both of which are in the class of the monumental type. The Market Street installation is the most pretentious effort yet displayed to coördinate the complicated conditions to be met in lighting a wide, busy thoroughfare. There are four trolley tracks with overhead wires attached to the usual poles at the curb. These poles have been given a very fine decorative treatment, having an octagonal base and tapering series of bands of ornament in low relief. The bands each represent a scene from California's history and were executed by the sculptor Putman. Advantage was taken of this fine work when it became necessary to modernize the lighting of the street and a cluster was designed to take three ornamental luminous arcs which was executed by the sculptor Leo Lentelli. One point which gives these trolley-pole lighting standards a solid, dignified appearance is their uniformly vertical position. Nothing so disarranges the orderly appearance of a street as to have a row of poles which slant out of the vertical. The generally horizontal lines of cornices, moldings, and curbs and vertical lines of building fronts, corners and columns are thrown sadly askew by engineers who insist that trolley poles must have a rake. The Market Street poles are an excellent example of what may be done if a pole is selected which is heavy enough to have a factor of vertical assurance. Some cities are going to spend much more than their original poles cost when it comes time to utilize them as lighting devices and they have to be reinforced and plumbed like the other architecture of the street.

Fig. 4, showing this standard, is one of a poster made at the time of the inauguration of the system when an elaborate carnival filled the streets of San Francisco with an overwhelming crowd of merrymakers who came to see the Path of Gold.

The Business Triangle of San Francisco is a district just west of Market Street. This district has been lighted with standards carrying two ornamental luminous arcs at a height of 25 ft. The design is rather ornate Roman and as there are no other posts to complicate the layout of the spacing, the effect is very fine and dignified. Those sections of the installation which come in close relation to some of the shops and store fronts having richly decorated entrances are especially pleasing. Fig. 5 illustrates the original design, which has been carried out very faithfully in the final work, and a night photograph of one of the streets of the "Triangle" is shown in Fig. 2. Attention is called to the generally even illumination on the buildings. With this type of lighting one is impressed with the bigness of the thoroughfare. The lights become a secondary consideration because they are doing something besides making bright spots on the pavement—they are lighting the buildings which make the street.

Both these San Francisco installations are carefully painted in imitation of bronze and a specially tinted glassware is used to avoid the effect of glaring white in daytime, while at night this yellow tint lends a warm glow to the illumination. Taken altogether these systems come nearer to being "painted out" than any other large ones in this country.

The Saratoga System is a milestone on the road to good street lighting. It marks a very definite step in the use of the incandescent lamp for exterior illumination, both in the method of installation and electro-mechanical control. Saratoga is an old American town, rich with Colonial landmarks, and when the question arose as to the decorative period to be used in the design for the lighting standards, it was quickly determined to use the Georgian. Broadway, the avenue lighted, is about 80 ft. between curbs with sidewalks which vary from 20 to 30 ft. wide. It is lined with grand old elm trees and has an interesting turn and varying grade. For a short period each summer Saratoga needs all the light it can flood on its streets to accommodate the night life, and standards having two Duo-lights each were installed at intervals of 120 ft., balanced opposite. In preparing the design, the effort was made to have the supporting shaft as slender as would be compatible with mechanical consistency and still be of a diameter which would gracefully support two units of the size of those necessary to house both a 250 c-p. and a 1000 c-p. lamp in each globe 20 ft. above the roadway. The globes, which were specially produced for this installation, are of an urn form not unlike some of the vase forms designed by Hepplewhite; in fact, the general design of the standard is in the Hepplewhite style. When the installation was complete, all unnecessary poles were removed from the street so that the symmetrical spacing of the lighting standard gives an interesting contrast to the

Fig. 9. Lighting Standard. State Street and Broadway, Salt Lake City, Utah. Three 6.6-amp. Luminous Arc Lamps

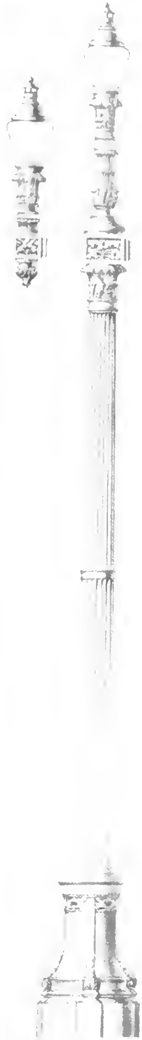

Fig. 10. Design of Three-light Ornamental Luminous Arc Standard for Use on Main Street, Salt Lake City, Utah

Fig. 11. Two-light Trolley-pole Stand ard Designed for Use in the "Loop," Chicago, Ill

uneven and natural curving of the tree trunks and branches. The turn of the street with its slight dip and non-uniform grade gives a most happy and pleasing effect when the lights are seen through an occasional branch which may hang low. The verde green color with which the standards and metal parts are painted aids in making them fit their place.

The design of standard prepared for the city of Augusta, Ga., is on similar lines and of the same general dimensions as the Saratoga standard but the requirements from a decorative viewpoint are more in keeping with the original scheme in San Francisco. Augusta, being in a cotton country, an attempt has been made to introduce a decorative treatment which makes an appeal to local sentiment. Fig. 8 illustrates the design proposed, in which may be seen the effort to use the cotton bolls, scenes on the base representing an old cotton gin, a press, or a picking scene.

Standards Combining Lighting Units with Trolley Poles

This method of lighting streets having trolleys with overhead wiring seems to be the easiest solution to the problem of keeping them as clear of superfluous impedimenta as will meet practical needs. If trolley suspension wires cannot be attached to buildings (and they can be in many cities by concerted action on the part of civic improvement organizations) then use the trolley poles for as many purposes as possible by converting them into lighting standards as well as supports for mail and fire alarm boxes or street signs.

The most elaborate attempt to give a street a semblance of orderliness and still retain the trolley pole was accomplished in Salt Lake City by the installation of the ornamental luminous arc system on the existing poles. Main Street, Salt Lake, is the most brightly illuminated street in this country. There are three lamps to a pole as shown in Fig. 10. It will be noted that the shaft is rather large in diameter, this being caused by the poles having been originally set out of plumb. The tapering shaft takes care of nearly three inches of rake, which in many cases could not be overcome by re-setting the poles since the bases were set in concrete and built into subcellar walls or between drains or other underground structures.

The street is so wide that it was most advisable to place the cluster of lights above the trolley suspensions. In narrower streets this is not always advisable for it would not lend itself to a very successful decorative effect. The Salt Lake City standard is of great size but the street is of such character as to warrant its use. This system is to be extended in the near future while another important installation is in progress of manufacture for the same city. State Street is a fine wide avenue, as are all Salt Lake City's thoroughfares. It leads south from the Capitol building which is seen on the high bench of the Wastach range, below which the city lies, and when illuminated will form a fine ending for the pretentious lighting of the avenue which leads up to it. The standards will be constructed of encased trolley poles with an ornamental base, but instead of a group of three lamps above the supporting wires, one lamp will be on top and two carried on brackets below the supporting wires.

This gives the standard a less lofty appearance, and as the street has few high structures the main mass will be down where it will not dwarf the buildings and the greatest illumination will be on the sidewalks and sides of the roadway. The center, or top lamp, will tend to smooth out any unevenness caused by the grouping below and will be used for all night service, the lower lamps being shut off at midnight. This is an excellent method of maintaining a pleasing effect on the street for it assures a generally even illumination, although of lower intensity.

There are certain possibilities for the decorative treatment of the trolley pole standard; for example, the standard with two lights designed for use in the Loop and extensions in Chicago carries the lighting units at an elevation of eighteen feet, while the pole is carried high enough above the trolley suspension points to give a more tapering finial than is usually found. This means of introducing an element of grace is utilized in the designs proposed for Oakland, California, and Elyria, Ohio. These three designs are all rather simple direct efforts to accomplish a given mechanical requirement in a reasonably passable architectural manner. By that is meant that the trolley pole is not being dressed up to look like a lamp post and a lamp post is not being designed to have a pole projecting from the top of it on which to hook a collection of wires, but acceptance is frankly made of the existence of the trolley pole and the lighting device necessities and an effort made to produce something that will do the work and not offend the sensibilities of those who are trying to make the streets of our cities more pleasant to behold. The decoration of the Oakland design is suggested by that of the new City Hall, in close proximity to which many of the standards will be installed, the oak leaf being used in relief in the bands. No attempt is made to cover the acter except that it is unconventional and is an effort to produce an ornate pole with lighting brackets which do not have a patched or stuck-on look. If these can be made to have the appearance of growing in place they will at least avoid the harsh mechanical lines so


Fig. 12. Design Suggested for Use in Oakland, Cal.

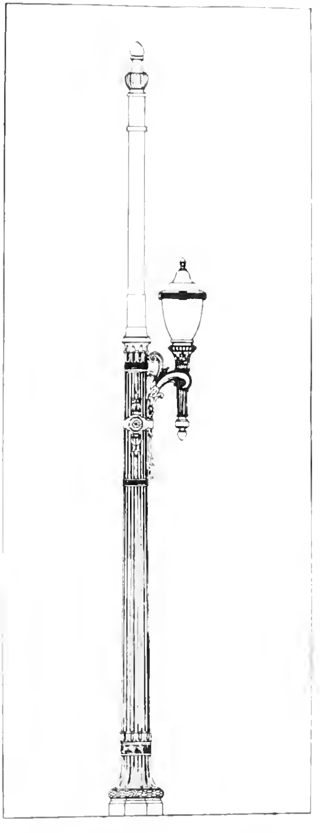
Fig. 13. Single-light Bracket Mounting on a Trolley Pole so Designed That it May be Amplified as Shown in Fig. 14


Fig. 14. A Two-unit Bracket Mounting for Use on the Trolley Poles of Important Streets

pole but the base has an interesting form, in that it is rectangular in plan to accord with the narrowness of the sidewalks. Space is provided in the long way to take care of cutouts. The design of the standard for Elyria contains no special architectural char-

often encountered in places where lighting units, as an afterthought, have been attached to poles or buildings.

All lighting apparatus of the sort fastened to and becoming part of the trolley pole should be as simple as possible. Repetition com-

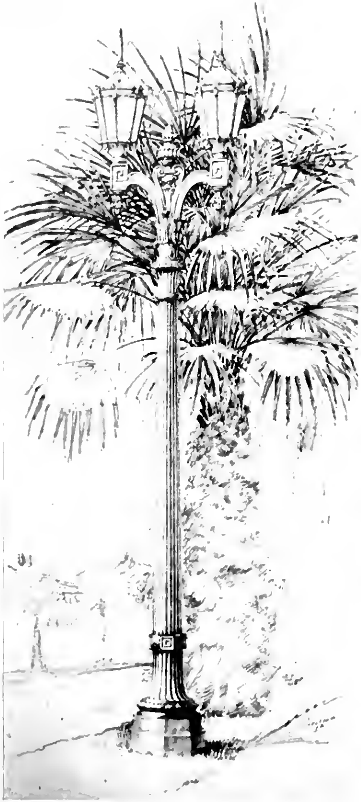

Fig. 15. A Type of Standard Designed for Use in Boulevards of a Formal Character

Fig. 16. A Boulevard Standard, Cleveland, Ohio. The arm carries the lantern beyond the curb line to force auto traffic far enough from the post to prevent collision. At cross roads the ornament just above the base is fitted with a red bull's eye

Fig. 17. Another Standard Designed for the Same Purpose as That Shown in Fig. 15

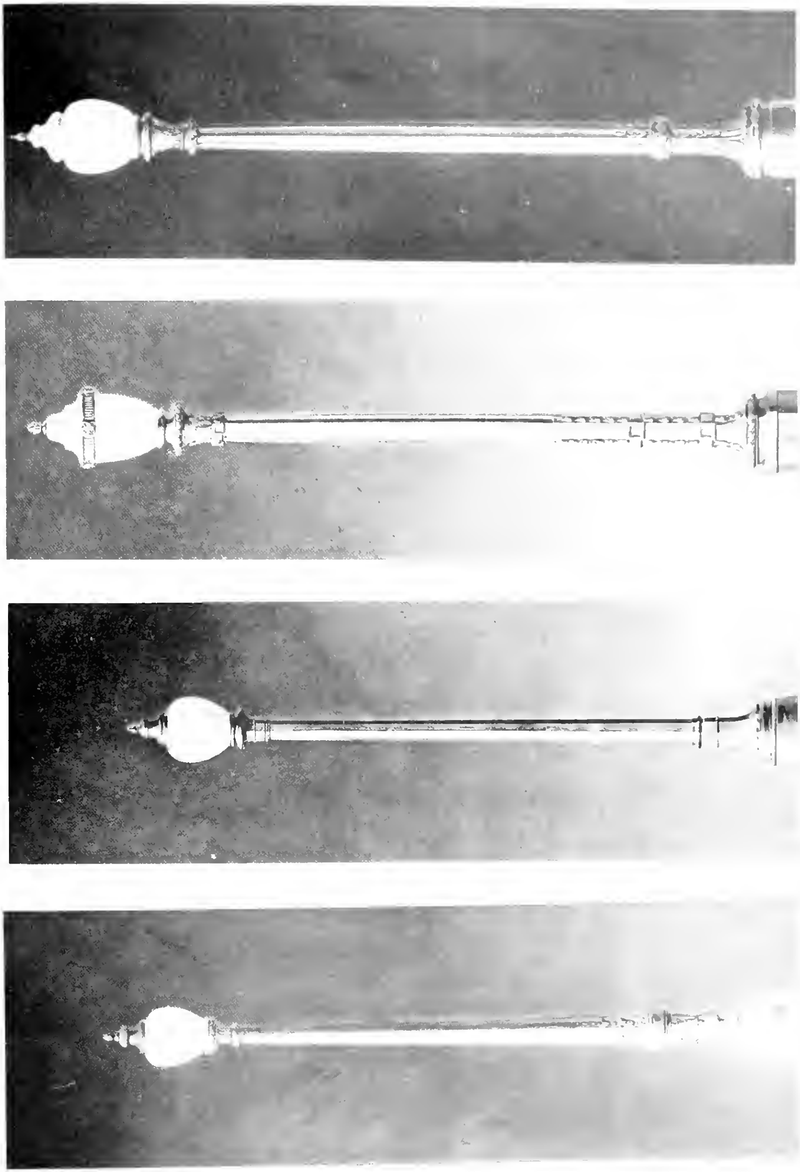

Fig. 18. Some Types of Recent Design in the Smaller Sizes of Lighting Standard

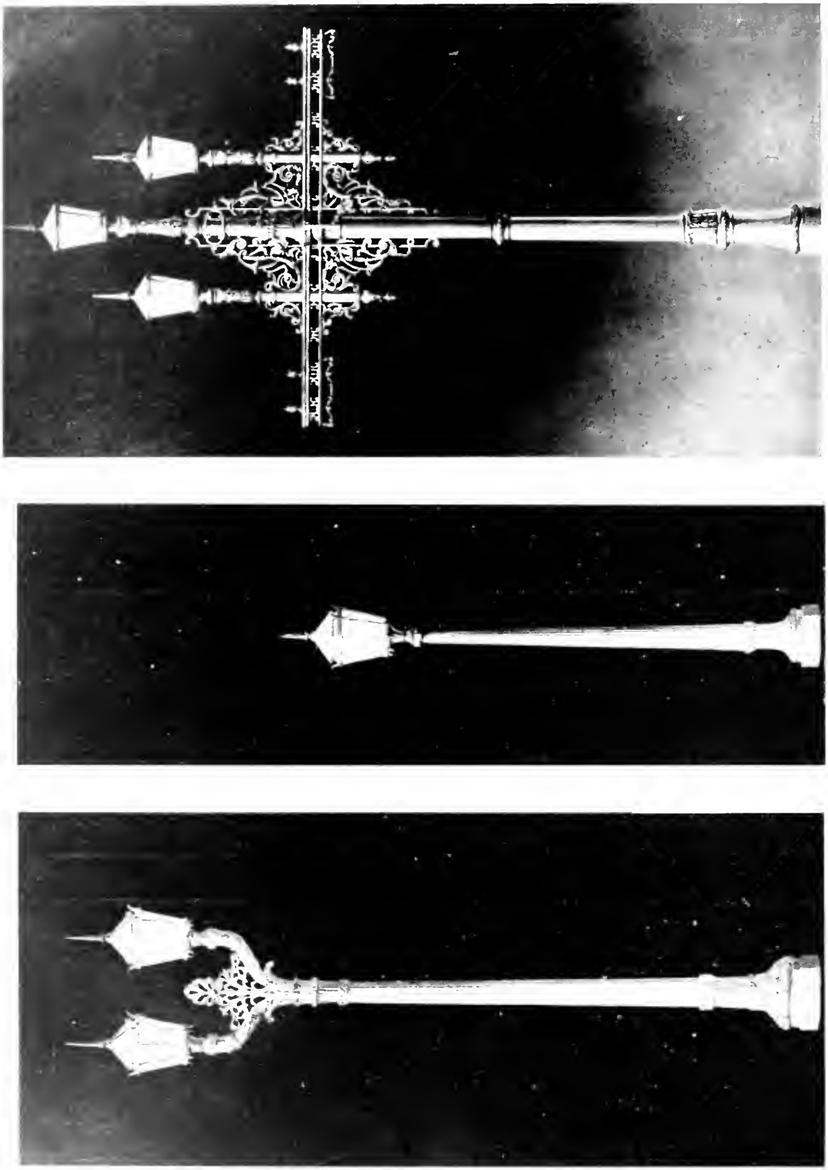

Fig. 10. Various Types of Standards Using Lantern Units

plicates matters enough as far as the decorative effect is concerned so that it is most advisable to avoid the use of free ending ornaments, thin wrought scroll forms or extra lights which do not do any of the necessary illumination work. Many of these details look pretty on a drawing but when made up on the street they soon become taudry through lack of proper upkeep, bent from accidents, or if extra lamps are attached they seldom remain long in use.

The single bracket on a trolley pole may be successfully treated as is exemplified by those recently installed on State Street, Chicago. This type also looks well with an ornamental base. The base is especially useful where an accessible cutout or transformer is needed. It might well be noted that the State Street brackets were installed in a section of street which had somewhat run down. The buildings are all fairly modern and of good size but were dark and dingy from an accumulation of smoke. The street was transformed when the lighting was modernized and the buildings all painted a light tint.

Boulevards and Open Areas

Boulevards of the class of Hollywood in Los Angles or Avenida 5 in the Reparto Miramar, Havana, may be successfully lighted by the employment of cluster type standards. The types recommended for these places are shown in Figs. 15 and 17 the first being of a design which will blend easily with the style of architecture in vogue in the Hollywood district and the second in the spirit of the designs of the villas being constructed in the Miramar district. The boulevard is generally tree-lined and will easily stand quite a rich decorative treatment. Rows of clusters of lights always give a happy gay effect, and as a high intensity in such places is not always necessary the fact that there are many spots of light will give the impression that there is more illumination than there really is.

As open areas such as city parks, band concourses, or bridge approaches must really have light, the units may be of the cluster type with fairly high intensity, or of the single type with sufficient intensity to illuminate a wide area. The spacing of the standards in the civic center in Denver is excellent, the lighting devices being clusters on stone bases. The slim and graceful lines of the post in use in Congress Park, Saratoga, lend a fine note of character to the gardening. This post is designed in the same style as the standards for the main avenue which skirts the north side of the park.

Business and Residential Districts

Many designs of lamp posts, which are good in silhouette and ornament, have been prepared and a number of them made for stock use by manufacturers. They are generally based on classic lines so that they can be used on almost any street having buildings of the modern trend in the architecture of business fronts. Several of these are shown in Fig. 18, with the glassware which is available or standardized.

The lantern shown in Fig. 19 is a recent development and is made with the idea of meeting the requirements of cities which are far from the source of supply of standard globes and where the breakage of a panel can easily be replaced. The cost of shipment of large globes is such an important item in the maintenance of an installation that this unit should appeal to engineers, especially for foreign work, as the device is designed to be shipped knocked down. From the standpoint of ornamental value the lantern is of importance. It will be appropriate with almost any of the Classic or Renaissance poles and has a use which the vase or urn shaped globes cannot replace. It looks well, either singly or grouped, and can be applied as an accepted ornamental form as pendent or vertical.

The lighting of extremely narrow streets is most effectively accomplished by the use of brackets either attached to the wall, as done in the old parts of Havana where the illuminant is gas piped through the building, or as proposed for Santiago, Chili, where the lantern will be used on a crook attached to the building and the feed wires carried underground.

Methods of Financing Street Lighting

By Louis Friedmann

Chicago Office, General Electric Company

Street lighting in general has failed to keep pace with other civic improvements, not because of any lack of advancement in the art of illumination, but because there has been applicable no fundamentally correct method of financing the installation. As the solution, the author of this article recommends that all States amend their improvement laws to include street lighting; then there will be available a method of financing which will enable any city to obtain such a degree of illumination as is required, and at the same time obtain an ornamental system which will harmonize with the architectural surroundings. This is especially important in view of the City Beautiful movement which is being advocated throughout the country.—Editor.

Suspending a lamp at each street intersection has for many years been the typical method employed in lighting our streets. Such systems are usually installed and operated by the public utility company, which charges the city a certain fixed sum per lamp per year for lighting the streets. The candle-power and number of lamps which the utility company can supply for this purpose are governed by the amount of money the city appropriates for street lighting.

Municipalities as a general rule do not, and oftentimes cannot, appropriate sufficient money to obtain better street lighting, the tendency having been constantly to reduce this appropriation, thereby forcing economies rather than making improvements; hence, progress has been retarded and street lighting has not kept pace with other civic improvements.

Fortunately, however, the increased efficiency of light production during the past few years has compensated for the decreased funds appropriated, so that while economies have been effected there has also been some improvement, but in general it is still inadequate.

The increasing number of automobiles and the greater use of our streets at night make necessary increased street illumination. Improved results could be obtained by increasing the candle-power of the existing lamps, or by using a larger number of lamps per block, but both methods naturally increase the cost, which oftentimes is not permissible under the prevailing method of providing funds for the purpose by city governments.

These facts have been well recognized by our business men, manufacturers, and civic authorities, who, realizing the great benefits derived from a well lighted street, have during the past ten years employed various co-operative methods of providing the necessary funds to obtain better street illumination in the business district, commonly known as "White-Way" or "Boulevard" lighting systems, which consist of ornamental lamp posts evenly spaced along the curb of both sides of the street and equipped with suitable lamps which are fed from a system of underground wiring.

This system of lighting has grown to be very popular, not only for business districts but for residential sections as well, because it combines utility with ornamentation, thereby producing adequate street lighting with ornamental lamps and posts which become a permanent improvement to the city.

The rapid growth of this system during the past few years indicates that it will eventually supersede the system of overhanging lamps; in fact, it is evident that the ornamental post system would be in more general use today had there been available a more satisfactory method of financing its cost.

It is principally the installation or first cost of such systems that requires a means of financing; the maintenance cost is comparatively low and is usually paid out of the general funds of the city.

The principal methods of financing which have been employed are:

(1) Popular subscription among the business men or property owners, or both.

(2) Installation by the utility company which in turn charges a slightly higher rate for current to amortise the original investment.

(3) Financing by commercial clubs or other civic organizations, which in turn prorate the cost against the members of the organization.

These several plans of financing have served their purpose admirably, but are open to certain objections and limitations and are not fundamentally correct. The practice of the central station entering into contracts with individual property owners or merchants has been generally unsatisfactory. Assuming that the street is initially fairly evenly illuminated, which is seldom the case, in the course of a few years many contracts are cancelled leaving blanks in the illumination effect and unproductive equipment in the hands of the central station.

This form of street lighting is a public improvement, and although only a portion of the city is so improved the city at large benefits.

It is therefore perfectly obvious that to install an ornamental lighting system which will be in keeping with the city and its natural progress, there must be adopted a more basic and equitable plan of financing to provide the necessary funds; and since the installation is of public benefit, it should be financed in the same manner as other public improvements.

Property upon a street so improved is more valuable than property on a street where there is no such electric light. In fact, property is benefited quite as much by adequate lighting as it is by water mains or street paving.

In some states, where this matter has been given thought, our legislators realize that street lighting is a public improvement and have amended the Improvement Law to provide for the installation of a street lighting system; this to be paid for in the same manner as other public improvements, by levying a special assessment against the abutting property on which the improvement is made.

Some of the states which have already passed such acts are: Alabama, California, Indiana, Iowa, Minnesota, North Dakota, New York, Ohio, Wisconsin, and Utah.

The existing Improvement Laws in some states are broad enough so that street lighting, being interpreted as a public improvement, has been installed and paid for under the law. However, it is far better, in order to avoid any possible controversy, to amend the Improvement Law and to include in the statute a definite act making street lighting a public improvement, as it is a fact that the Appellate Courts have been called upon in several instances to pass upon the validity of such improvements contemplated under the Improvement Law which does not definitely include street lighting.

By including street lighting as a definite act under the Improvement Law, the method of financing the system is immediately solved, as it enables any city within the state to obtain in a legal and orderly manner adequate street lighting which will be an improvement to the city. Under such laws any part of the city or the entire city may be so lighted, at the discretion of the city and its property owners, as there is readily available a method of financing which will enable the installation of a street lighting system that will furnish any degree of illumination or ornamentation.

The usual procedure to obtain an ornamental lighting system under the Improvement Law is as follows:

(1) A petition asking for this improvement and signed by a certain percentage of the property owners interested is filed with the Common Council or other governing body.

(2) Upon receipt of the petition filed in accordance with the law of the State, an ordinance is introduced in the Common Council providing for the improvement.

(3) This ordinance instructs the City Engineer to prepare plans and specifications covering the installation of the lighting system. It also determines the proportion of the total cost which is to be assessed against the properties and that which is to be paid by the city, unless otherwise stipulated by the law.

(4) A public notice is then made of the contemplated improvement by advertising the fact in the official newspaper of the city, and after a certain time has elapsed as provided for by the statute, and no protests to this improvement are officially presented to the Common Council, the city then advertises for competitive bids, which are received in due form and the contract awarded to the lowest responsible bidder.

(5) The cost of maintenance is usually borne by the municipality and paid for out of the general funds of the city.

While the foregoing covers the procedure most generally followed, there are some instances where the initial movement differs, for example:

In North Dakota, the Common Council is empowered by the law to introduce a resolution for the installation of a special street lighting system without the necessity of a petition from the property owners.

In Wisconsin, the law requires a petition of owners of one-half or more of the taxable frontage on any street or part thereof designated by the Council as an ornamental lighting district; or, the Common Council may on its own initiative and without a petition of abutting property owners provide for the lighting of streets by means of an ornamental system.

In Montana, the law authorizes the Common Council to create special improvement districts for lighting streets, after first having passed a resolution of the intention to do so, thereby giving the property owners the opportunity to object to the improvement before the ordinance is passed providing for it.

In the states where such laws have been passed, the system is installed not only in the business district but is extended into the residential sections as well. In fact, some cities are already entirely lighted in this manner, which systems were installed and paid for under the Improvement Law.

Street Lighting Expenditures

By A. F. Dickerson

Illuminating Engineering Laboratory, General Electric Company

Per capita expenditures in practically all municipal departments have greatly increased during the past decade. One exception has been street lighting. Ever increasing traffic and the popularity of night recreation have so congested the streets of our cities that greatly increased illumination has now become a necessity. This article analyzes the division of the "tax dollar" and points out the fairness and economy of the assignment of a larger proportion of it to street lighting. By charts and tables it also presents per capita expenditures for street lighting by cities and by states so that one may locate at a glance sections of the country that are deficient or progressive in this respect.—Editor.

Street lighting is indicative of progress. Bright lights and clean streets stand for prosperity and civic pride, whereas the dim dingy town is immediately classified as "dead." Good lighting is good business; and when it is allowed to lag behind the march of progress, progress itself will soon be retarded.

Statistics for the cities in the United States show that there have been large increases in practically all departmental expenditures, in fact in some cases per capita costs have nearly doubled in the past ten years. The exception has been street lighting where there have been only slight increases in budgets, the per capita cost remaining almost constant. However, thanks to science, great progress has been made in the efficiencies of illuminants and in the design of street lighting accessories, so that today, in spite of increased costs and apparently inflexible budgets, our streets are far better lighted than they were ten years ago. But ever-increasing traffic and the popularity of night recreation have so congested the streets of our cities that many lighting systems that were considered good in their day are now woefully inadequate. It is opportune that an investigation be made of municipal finances to determine just "where the tax dollar goes" and whether a fair proportion of it is expended on street lighting.

Street lighting rates are generally low but, based upon old investments, usually a fair return is being realized. However, the income from new installations at present rates is not sufficient to encourage central stations to make large expenditures for extensions. In some localities, increased rates have been granted, and without doubt many more applications will receive favorable consideration after more thorough investigation has been made. It is the purpose of this article to show by charts and otherwise that street lighting budgets form only a small portion of total municipal expenditures, and, in view of the evident necessity, a slight increase is warranted in satisfying a popular demand for more light.

Fig. 2 shows how the tax dollar in 1919 was divided among municipal departments. Groups of cities are classified first according to population and finally an average chart for all cities of over 30,000 population is given. It is rather startling to see that only 3.4 cents of every dollar is spent on street lighting, the necessity that is so essential to the progress of every community. Twenty-one cents goes for "protection." Does it not

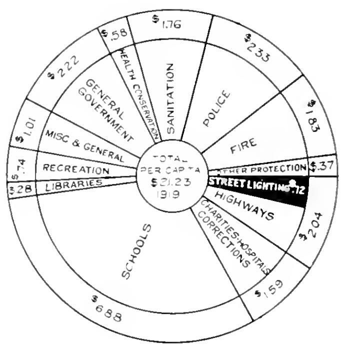

Fig. 1. Of the $5.25 per capita which the average city of over 30,000 annually spends for safety and protection, only 72 cents is for street lighting. The overall service purchased by the $5.25 expenditure could be greatly improved by a reallotment which would increase the street lighting budget but a few cents

seem reasonable that, at least in some cases, this might be reduced by one or two cents and the money spent to better advantage in lighting? Bright streets make better streets—better for the public—and are a distinctive aid to both the police and fire departments.

Fig. 1 gives the actual expenditures for the same items as listed in Fig. 2. It is of interest to note that the average per capita cost for street lighting in 1919 for the 227 cities in the United States, with populations over

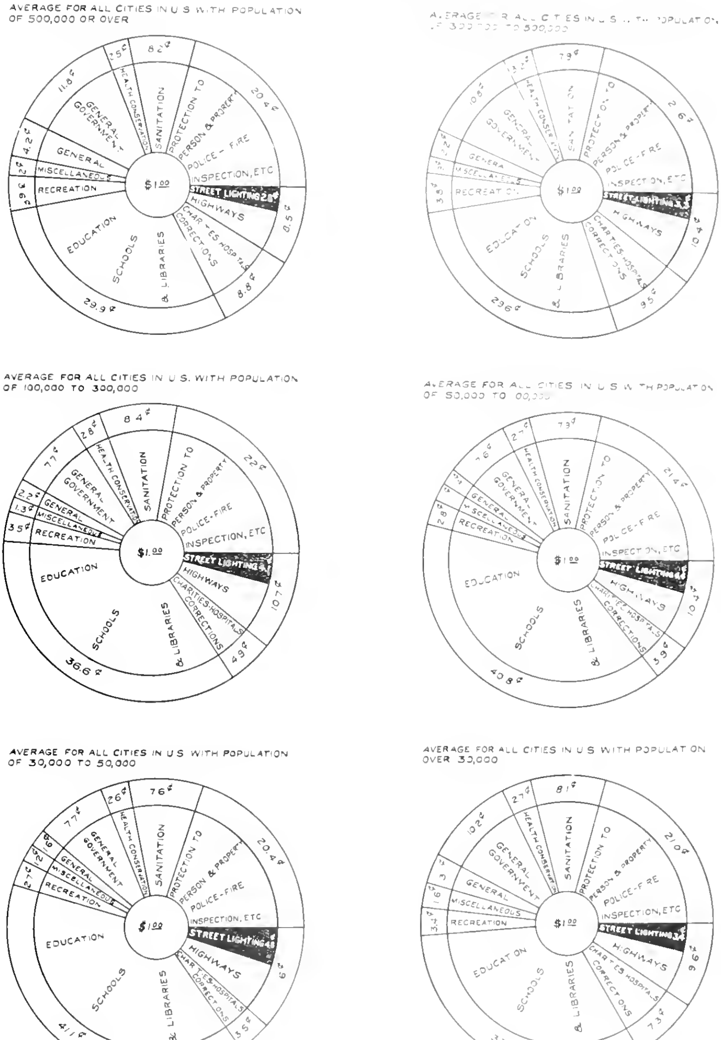

Fig. 2. Charts Showing the Division of "the Tax Dollar" and the Portion Devoted to Street Lighting in the Various Size Cities of the United States

Calculated from "Financial Statistics of Cities" for 1919, issued by United States Bureau of Census

TABLE I

SUMMARY BY CITIES

Number of Cities	Area	Population	Budget	Street Lighting	Street Lighting Per Cent of Budget	Street Lighting Per Capita	Street Lighting Per Square Mile
		1,000,000 or over					
3	655.27	10,141,911	$459,918,279	$5,631,554	1.23	$0.56	$8,430
		500,000 to 1,000,000					
7	650.3	4,720,883	115,446,117*	4,050,617	2.43*	0.86	6,230
		100,000 to 500,000					
31	1,040.73	5,975,725	150,270,033	4,276,565	2.84	0.715	4,100
		50,000 to 100,000					
36	550.84	2,503,221	44,924,882	1,731,228	3.86	0.692	3,140
		20,000 to 50,000					
119		3,674,745		2,881,235		0.785	
		10,000 to 20,000					
199		2,738,131		2,370,965		0.867	
		5,000 to 10,000					
352		2,130,422		1,810,823		0.848	

* Five cities only.

30,000, was 72 cents. From recent incomplete investigations, including 747 cities of over 5000, the average was found to be 71 cents.

In order that a glance may determine the states that are deficient in street lighting, a map of the United States, Fig. 3, indicating per capita street lighting costs, has been prepared. It has been generally conceded that for good street lighting the average per capita expenditure by the municipality should be not less than one dollar, yet there are only nine states over 90 cents, four of which exceed a dollar. The ratio of the maximum to the minimum is three to one.

In Table I the cities are classified according to population and only average figures given. The percentage of street lighting to total

○ PER-CENT POPULATION OF STATE IN CITIES INCLUDED (CITIES UNDER 5000 POPULATION NOT CONSIDERED)

Fig. 3. Map Indicating Average Expenditure for Street Lighting (dollars per capita)

From 1921 Transactions of the N.E.L.A.

budget is not available for cities under 50,000 but this figure will probably increase to nearly 10 per cent for cities of 5000. Naturally the expenditures per square mile will decrease with the population, mainly because there is less necessity for high illumination and there is less tax money available for this purpose.

There are a few cities spending over three dollars per capita for street lighting; the highest being $4.81. However, the average for the 50 best lighted cities is about $2.04. The fact that the cities of over a million population show a decreased per capita expenditure does not indicate that they have inferior illumination. They are more congested and from the tabulation it will be noticed that the expenditure per square mile of area is correspondingly high.

The yearly cost of street lighting will vary from about two cents per linear foot of street for the poorly lighted village to over five dollars for an intensive system such as is on Market Street, San Francisco. The latter figure may seem extravagant and it would be for a municipality, but such lighting is considered as a commercial investment and its cost is usually borne by abutting property owners or merchants. The average per linear foot for all streets in the United States, excepting the white-ways, will not be over five cents per year.

The stockholders of a city are its taxpayers and the success of a city as a business is reflected in increased real estate and property values. Again let us repeat "street lighting is indicative of progress." If it is a good investment for a property owner or merchant to pay over six dollars to light one foot of street, would it not be worth while for a city to consider paying over five cents?

White-way Lighting, Stamford, Conn., with 6.6-amp. Luminous Arc Ornamental Standards

Street Illumination Tests and Specifications for Contracts

By G. H. Stickney

Edison Lamp Works, General Electric Company

Because of the many sources of error which may be present when running a street illumination test, the author recommends that important decisions be based upon laboratory tests where exact conditions may be noted. Relative to the matter of drawing up a street lighting contract, he discusses what features may be included and what should be excluded in order that it be fair to both the municipality and the public utility. The reasons for these recommendations he furnishes in detail.—Editor.

Street Illumination Tests

The greatest care is necessary in running illumination tests on the street. There are so many factors which may lead to erroneous conclusions that it is of the utmost importance to scrutinize such tests very closely before final conclusions are drawn. With the exception of the so-called White Way Lighting, the variation from maximum intensity to minimum intensity, while proportionally very high, is numerically only a fraction of a foot-candle. It will readily be seen that a slight error will nullify the value of the whole test.

Some of the causes of error are as follows:

Too few lamps are tested causing too much weight to be given to the performance of an individual lamp. The lamp may not be in the proper position in the units which are being tested. This is particularly true where a refractor is used. In this case changing the position of the lamp would change the distribution curve, causing the maximum candlepower to come in an entirely different position than was intended and change the readings on the street. The current flowing through the lamps may also be high or low, due to the temporary fluctuations which are well known on any external circuit. For this reason, the central station should notify the man at the switchboard to note current conditions during the time of the tests, so that proper corrections can be made for any variations.

Persons inexperienced in photometry very frequently try to run street lighting tests and the personal error in reading, coupled with the inherent error in a portable photometer, may cause a wide variation from the true reading. In comparing the performance of several units, due consideration must be given to the reflection from buildings, shadows from trees, and the condition of the road surface. Important decisions should not be rendered on street tests run with a portable photometer, but should be based on laboratory tests where exact conditions may be noted.

Lamps and Specifications for Street Lighting Contracts

It is highly important that proper care be taken to insure high-grade service to the municipality. The street lighting service of the utility is always in the eye of the public and is an index of the service for other classes of lighting. Serious misunderstanding and disagreement have often resulted from incomplete, inaccurate, or indefinite specifications of street lighting units; therefore considerable forethought should be exercised in the preparation of street lighting contracts.

One of the first points to be noted is the necessity of differentiating between the specification of a light source and of a street illumination. Before closing a contract it is well to determine what type and arrangement of lamps will produce the desired illumination effect. This having been done, the specification should be drawn to describe as simply as possible the lamps and the lamp fixture equipment to be furnished, and the number of hours per year and per night they should be operated. Sometimes it is advisable also to specify the form of current supply to be furnished; i.e., whether alternating current or direct current, series or multiple. In general, however, such specifications should be omitted, as imposing unnecessary limitations. Provision should be made for locating the lighting units, but any attempt to prescribe actual illumination in the street will only complicate the contract and introduce indeterminate questions.

Individual lamps are bound to vary either above or below their rating. Where Mazda C or gas-filled lamps are considered, the true horizontal candlepower value is difficult to obtain, even in a laboratory, except with proper apparatus in the hands of experienced photometrists familiar with the lamp characteristics. Furthermore, the horizontal candlepower is not as fair a measure of the lighting power as is the mean spherical candlepower or the lumens. If tests are made on these lamps installed on the streets, results may be obtained that are inconclusive and offer no true criterion as to actual performance. The plane at which the measurements may be made, relative to the axes of the coils of the filaments, affects the readings and sometimes to a considerable extent. It is not advisable to rotate these lamps to get the average horizontal candle-power around a lamp, because it materially affects the convection of the heat by the gas in the lamp, and this in turn will cause the candlepower of the lamp to vary.

It therefore appears that the most logical way today to specify series Mazda lamps in a street lighting contract would be to rate them in mean spherical candlepower or total lumens (the total flux of light), without reference to watts, volts, or other electrical unit terms. The mean spherical candlepower of a series lamp can be very readily determined in a photometric sphere with the lamp kept stationary, and is a much more accurate measure of the light emitted by a lamp than the candlepower at any particular angle or direction.

Where multiple Mazda lamps are used for street lighting, the fact that the lamps are rated in watts and are so specified in the contract eliminates practically all difficulties in the fulfillment of a contract, because, while there may be manufacturing variation in individual lamps, any increase in efficiency of the lamps does not affect the wattage, the candle-power or the total light flux being increased. However, where multiple lamps are used, it is necessary to specify in some manner that the lamp, when installed, represents the latest product at the particular time of its manufacture.

Arc lamps for street lighting are designated first by their type: open carbon, enclosed carbon, flame, luminous or magnetite arc. They are rated next for the type of circuit upon which they are to operate: overhead or underground. Then follows the circuit current and the wattage of the lamp. For example, a luminous-arc lamp is available in three sizes: 4-amp., 310-watt; 5-amp., 388-watt; and 6.6-amp., 520-watt. This method of holding constant the current and wattage rating is advantageous to the municipality since it permits them to secure the increased illumination which results from the development of more efficient carbons for electrodes.

The incandescent fixture equipment should be more or less definitely specified, but the specifications should not always be enforced too rigidly in this respect. Improved equipment, that it might be very desirable to utilize, may become available during the term of a contract.

A street lighting contract must not only make allowance for variation in the manufacture of lamps, but also for the inherent depreciation of the lamps throughout life. Lamp manufacturers are endeavoring to their utmost to narrow the limits of variation from the nominal ratings of lamps, but the problem is difficult and highly technical in its character.

In regard to deductions for outages, it is quite within reason that the central station should be given sufficient notice to replace a defective lamp before deductions are made. Incandescent lamps, no matter how well patrolled, fail without warning and arc lamp electrodes may burn out prematurely. A patrolman may have observed the lamps on a street to be burning satisfactorily and immediately after leaving it one or even two lamps may fail. If a lamp fails, the central station should not be deemed liable to a deduction if it is replaced within 24 hours, or such a period as to allow a reasonable time to discover the outage.

Comparisons of prices charged in various cities for apparently similar service are apt to lead to erroneous conclusions, unless all the local circumstances are known and given full consideration.

It is fairly safe to assume that when a contract specification is so drawn that it correctly defines the character of the unit, the amount of light emitted from the lamp, deductions, etc., and at the same time allows for improvements in the art, such a specification is of real value to a city as a guide and relieves the officers of the operating company of much anxiety and suspense.

A factor that tends greatly toward the satisfactory fulfilment of a street lighting contract is the spirit of good will existing between the parties to the contract. The creation of such sentiment is advantageous in all business dealings, but is particularly so where street lighting contracts are concerned that often necessarily have to be drawn up in a manner more or less flexible as to their interpretation. It is fully as important to live up to the spirit as to the letter of the contract.

Street Lighting Distribution Systems

By E. B. Meyer

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The questions that arise in connection with the problem of installing distributing circuits for street lighting are ably answered in this article by Mr. Meyer who is an authority on the subject. His discussion includes both the series and the straight multiple systems, for while the series system for both arc and incandescent street lighting is the more common at the present time there are a large number of straight multiple systems in operation. The detailed information which he furnishes in regard to the various installation features for circuits in different types of localities should prove most useful to those who are engaged in this type of work.—Editor.

Considered from a distribution standpoint, a street lighting system will of necessity follow along the same general lines as the system in use for commercial lighting and power service and will be dependent to a large degree on the station equipment and local practice.

The investment necessary to supply a system of street lighting in many cases is such that the utility company for financial reasons must confine itself to an overhead system, except where there is an extensive installation of park or boulevard lighting, or where a complete underground system already exists.

The extension of street lighting to districts such as newly developed residential sections, streets or roads in sparsely settled districts, or small isolated areas has brought to the forefront the necessity of considering, under prevailing conditions, such additions independent of and possibly by some means entirely different from the existing street lighting systems in the more or less congested districts.

While the series system is the most common in this country for both arc and incandescent lighting, there are however a large number of straight multiple systems in operation. Several of the large cities, notably New York, operate on a straight multiple system because of the advantage of confining the service to the low-tension Edison current.

While local and economic conditions are factors which determine the choice of a system, consideration is being given more and more to the possibility of utilizing the existing commercial mains for street lighting from both the alternating-current single-phase 2200-volt form of distribution and the low-tension direct-current or alternating-current net work.

On a series system the number of lamps is usually limited so as not to exceed 5,000 volts on a circuit. This is especially desirable on open wire lines which run through trees and on business streets where grounds, breaks, or crosses with other wires are apt to occur. Care must be taken to provide insulation for at least twice that voltage, as a ground on any part of the line may increase the voltage from 50 to 100 per cent.

In Fig. 1 is shown a typical installation of a street lamp mounted on a pole fed from a series overhead system. For installations of this character it is considered standard practice to use a No. 6 weatherproof wire although No. 8 is also extensively used. The former size is adopted only on account of its additional mechanical strength. The series lighting wire is usually found on the end pins of the arms. There are two reasons for this

Fig. 1. Aerial Line Construction Showing Series Lamp Bracket Suspension

construction: one is that the street lighting wire is generally the first circuit on the pole and is set out on the end of the arm; the other is to keep it at a safe distance from the pole where transformers or other apparatus may be located.

In bringing the wire from the pin to the lamp the wires are run along the arm to the pole and down the pole to the lamp bracket on insulators. If a long boom is used the wire is hung from an insulator at the pole end of the boom to the lamp fixture. Here it usually terminates in an automatic short circuiting cutout. This cutout consists of a spring device which short circuits the lamp whenever it is lowered from the boom and again properly connects it to the circuit when the lamp is pulled up in position.

In Fig. 2 is shown a standard method used by a large central station company for arc lamp suspension. Duplex No. 8 flexible lamp cable is used from the rain loop at the open wire and run through insulators down the pole to the cutout mounted at the end of the iron pipe boom.

In underground systems a No. 8 wire is generally used, insulated with rubber, paper, or varnished cambric tape and covered with

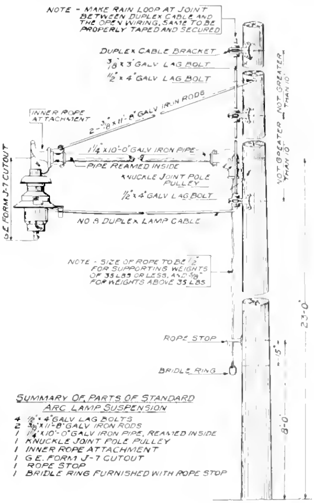

Fig. 2. Fittings and Standard Parts for Arc Lamp Suspension

a lead sheath. Some companies do not sheathe their rubber insulated cable of this type, but use a triple braid instead. It is good practice to run a duplex cable from the station or substation to the first lamp. If the lamps are located at reasonably short distances apart, a single-conductor cable may be used to feed each lamp and in this manner eliminate the splices which would otherwise be necessary to cut into the duplex cable. By using a multi-conductor cable where the number of vacant ducts is limited, several circuits may be brought out in one duct from the station to a distributing point.

Fig. 3. Installation of Armored Cable in Brick Paved Street

The necessity for a safe and inexpensive underground system in many of our small cities or towns and for parks, play-grounds, and boulevards of larger cities has brought about a great demand for steel tape cable. This cable is made in various sizes and is adapted for any voltage. The conductors are insulated with a rubber compound and taped. After the required number of conductors have been laid and covered with jute and tape, a lead sheath is applied and the whole served with jute over which the armor is then applied. This usually consists of two layers of steel tape over which is applied the asphalt and jute which serves for the outside or final layer.

One of the largest installations of this type of cable is in Central Park, New York City, where it is used for street and park lighting. Installations such as this have been in service in this country for a number of years and have operated very satisfactorily. The cable is usually laid about one foot deep in a trench of spade width as illustrated in Figs. 3 and 4. No reinforcement or protection is provided except at street crossings and roadways where there is apt to be heavy traffic. In such places it is customary to run the cable through an iron pipe or other suitable protective covering. Where the ground is sufficiently level the cable may be laid from the reel mounted on a pair of wheels.

No joints are made in the cable as it is usually looped in through the various lamp posts. Terminal blocks are provided in the bases of the posts.

Steel-tape cable being frostproof and waterproof may be laid just deep enough to prevent accidental damage or injury. Where the cable is used for street lighting the usual practice is to bury the cable in the street close to the curb just beneath the paving. Where the street is paved with brick, granite block, wood, or other forms of improved paving,

Fig. 4. Installation of Armored Cable for Park Lighting

the installation simply requires the removal of one or two rows of paving material and the cable is then laid several inches below the pavement, and the paving replaced.

Another method is to remove one course of brick or block next to the curb, lay the cable, and cover it with concrete to the pavement level. This method may also be used with asphalt or macadam, a shallow groove being chopped away and the groove filled flush with concrete. In either of these cases the cable is brought up to the lighting post, either under the curbing or through it, and up through a hole in the sidewalk.

Where obstructions of any kind are encountered in the trench, the cable is pulled under or around the obstacle. Where the light standards can be set upon concrete walks no other footing is necessary. The base can be set on the walk, holes marked and drilled, and the foundation bolts set in head down, bedded in lead, sulphur, or grout. A hole for the cable is drilled through the walk and another through or under the curb. The cable is brought up through, the standard set over it and bolted in place.

When there is no cement walk, or where the concrete is not strong enough, it will be necessary to build a concrete base or put in a cast-iron sub-base for the lamp standard.

In a conduit system of distribution for street and parkway lighting, tile, fibre, and stone ducts have been used, and while there is some difference of opinion among engineers as to which type of conduit is most suitable tile and fibre ducts seem to be most generally used. Fibre conduit in recent years has come into general favor and at present is standard construction and used successfully by a number of the large utility companies.

In some locations stone pipe is being employed to advantage, and its cost compares favorably with that of tile and fibre conduit.

In large cities the arrangement of street lighting laterals is a matter of importance because it forms a large part of the underground investment. A single conduit system with street lighting service connections is shown in Fig. 5. In some cases it is advisable to install duplicate conduit lines in the same street, as illustrated in Fig. 6, one conduit consisting of a sufficient number of ducts to carry all the main cables, and the other usually consisting of about four ducts on the opposite side of the street for distribution.

The desirability of installing duplicate conduits depends entirely upon local conditions and the width of the street. With the duplicate conduit system the lighting service or lateral connections are usually of a shorter length than in the single conduit system and the service holes are placed about 100 ft. apart.

Still another system, which is similar to the duplicate conduit system, is to provide crossings at each distribution hole from which the service connections and street lighting laterals are run.

In many suburban districts what is commonly known as the "sidewalk system" of distribution is used. The conduit is laid in the grass plot between the curb and the sidewalk with hand holes conveniently located from which the lateral pipes lead to the street lighting standards. The type of hand holes used in this system is illustrated in Fig. 7. Sometimes pull boxes are laid below the sidewalk level, their exact location being kept so that they may be accessible in case of trouble. The box shown in Fig. 7 is well adapted to this type of construction.

The duct may be either of fibre or iron pipe, the fibre duct being considerably cheaper than the iron pipe. It is not necessary to lay the duct in concrete and a special sleeve may be employed which has sufficient strength to insure proper alignment of the duct during the refilling of the earth.

Several methods are employed to carry the underground circuit along the street but the most common is by running lateral pipes from the manholes to the individual poles. In cases where the lateral pipe terminates in the base of an iron pole, a cutout is installed. There are a number of types of cutouts made, all of which operate on practically the same principle, i. e., a switch to short circuit the incoming wires when the lamp is cut out. Some of these switches operate in oil. They should be insulated from grounds for at least twice the line voltage. From the cutout to the lamp or lamp compensator, a duplex rubber and braid cable is often used. This cable is heavily insulated to ground but it is not necessary to have between conductors much more insulation than that required for the lamp voltage.

In cases where it is not advisable to have the full line voltage impressed on the leads running up through the pole, a series transformer is installed in the base of the pole to transform to the voltage and current required by each individual lamp. The use of these transformers has been adopted as standard practice by several companies on their underground distribution systems where iron poles are used as lighting poles. The transformers are enclosed in a steel casing, weather and waterproof and may be used on poles, in manholes, or even buried in the ground at the base of a pole. They will operate on short circuit for an indefinite time without danger of overheating. With them it is possible to use high-efficiency series lamps where high potential is undesirable. It is not necessary to use a cutout in addition to this transformer and the expense of heavy insulation to and in the pole is saved. No film cutout is required as each lamp is independent of the others in the circuit. The transformer also has the advantage of limiting the current to the lamp when surges occur on the line.

With the use of another type of series transformer, it is possible to operate a low-potential series circuit, similar to a loop, in connection with the main series circuit. This transformer has a one-to-one ratio and is used extensively to avoid the necessity of installing a multiple system. Its chief advantage, however, is that being a part of the main circuit all lamps on the secondary circuit come

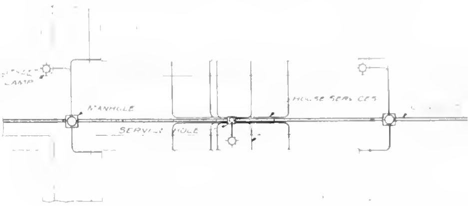

Fig. 5. Single Conduit System Showing Manholes, Service Holes Laterals, and Street Lamp Connections

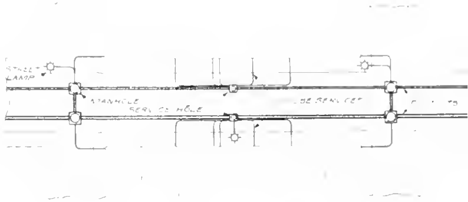

Fig. 6. Double Conduit System Showing Manholes, Service Holes, Laterals, and Street Lamp Connections

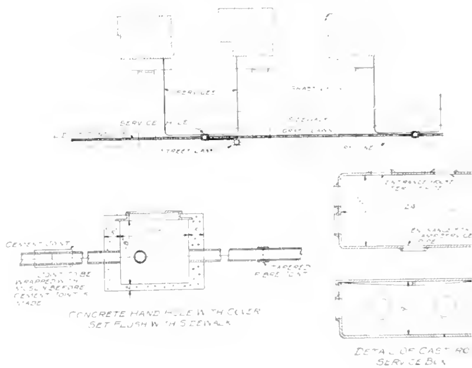

Fig. 7. Conduit System of Sidewalk Distribution

on at the same time as those on the main circuit without any switches or other apparatus. It is used chiefly on bridges, safety islands, in alleys, parks, house lighting where constant potential is not available nearby, and other places where a high potential is undesirable. This transformer will also operate indefinitely on short circuit.

In routing series circuits the best practice is to run only one leg of the circuit on each street so far as practicable in order to save copper. On certain lines it will not always be possible to follow this arrangement throughout, and at such points a short circuiting switch can be installed for test purposes or for cutting out parts of the line for repairs.

Iron poles in all cases should be well grounded either to a driven ground or to the lead sheath of the cable which in turn should be grounded at different points or bonded to other cables in the manholes.

There are many different styles and kinds of ornamental poles, each depending chiefly on the ideas of the local authorities and the operating company. In selecting an ornamental iron pole there are several items to consider, among which is safety to pedestrians in case the pole should be struck and break. The pole should not have too much weight near the top so as to make it top heavy, should be designed to harmonize with surrounding structures, and should be located far enough back from the curb to avoid interference with street traffic. Enough space should be allowed in the base of the pole for cutouts, transformers, or other apparatus.

As an aid to traffic regulation in addition to the usual street lighting of high intensity, there is a new field of lighting in the illumination of busy or dangerous street intersections. The type of traffic post used in these locations is usually of a simple design, such as illustrated in Figs. 8 and 9.

Fig. 8. Traffic Post Installation on Safety Island in Busy Section of City Street

Fig. 9. Special Type of Post Used for "Silent Policeman" at Street Intersection

Fig. 10. Combination Ornamental Iron Pole Used for Trolley Span Wire and Street Lamp Suspension

The adoption of a combination pole for trolley and lighting purposes has made a great improvement in the general appearance of streets as the pole carries lighting and trolley wires, thus decreasing the number of poles in the street. Fig. 10 shows a standard trolley and lighting pole adopted by one of the large cities of the East in which the old trolley poles and some of the lighting poles were removed and replaced by the combination pole. The general appearance of the street is much improved as compared with its former condition, owing to the decreased number of poles.

The Luminous Arc Lamp

By R. B. Hussey

Street Lighting Department, General Electric Company

The author traces the development of commercial arc lamps from the open arc, enclosed arc, and flame arc to the modern luminous arc lamp at present installed in our large cities for ornamental and utilitarian lighting. Essential information regarding the character of the arc, types of electrodes, operating features, and the quality of light as relating to the luminous arc lamp are discussed in detail and the characteristics of the lamp which particularly fit it for street lighting are pointed out.—Editor.

The first arc lamps manufactured and used for street lighting were the so-called open burning carbon arcs. These operated on direct or alternating-current circuits and were usually connected in series. The electrodes were made of hard coarse carbon and were usually copper plated to obtain better conductivity. The arc burned in the open air with an outer globe which served to protect the arc from the wind rather than to provide diffusion of the light. This type of lamp was first commercially manufactured about 1876 and held the arc lighting field until displaced by the so-called enclosed carbon arc which was first put on the market about 1895.

In this lamp the arc was enclosed in a small tightly fitting globe so that the arc burned in an atmosphere to which the access of oxygen from the air was restricted. On this account the carbons were consumed very much more slowly and the arc burned more steadily. It became necessary to use carbons of a better quality but, since one trim would last about ten times as long as with the open-arc lamp, the slight difference in cost of the carbons was more than offset by the smaller number required and the reduced labor cost of trimming. Shortly after the beginning of the present century, two new types of arc lamps came upon the market; the flame-carbon arc and the metallic or magnetite arc.

The former used instead of pure carbon a carbon treated with various metallic salts which evaporated into the arc and produced an arc stream of high luminosity. In order to obtain good efficiency, however, a large amount of these salts had to be consumed and the life of a single trim was not much greater than with the old open burning carbon arc although the efficiency was several times greater. This lamp was later superseded by the enclosed flame-carbon lamp in which a similar line of development was carried out to that employed in developing the enclosed carbon arc from the original open-carbon arc. A tightly fitting globe was provided for restricting the access of oxygen to the arc and a large metallic chamber was placed just above the arc to receive and condense the metallic oxides which would otherwise condense on the globe and obstruct the light. This lamp for a number of reasons did not long remain a commercial article.

Fig. 1. Arc and Tips of the Electrodes of the Luminous Arc Lamp. The arc rises from a molten pool of oxides, spreads out, and furnishes all the light emitted from this type of lamp

The only form of arc lamp which has survived through the developments of the last four decades is the so-called magnetite or luminous arc lamp. It was first put on the market about 1903 and is still used in most of the larger cities throughout the United States. Some features of this lamp are entirely distinct from other arc lamps and it may be described somewhat in detail. The upper electrode consists of a rod of solid copper which is relatively non-consuming. The lower electrode consists of a mixture of various metallic oxides packed into an iron tube and it is this electrode that furnishes the material for maintaining the arc and giving the light.

As in the case of the flame lamp it is the arc stream and not the tips of the electrodes that furnish the light. Fig. 1 shows the appearance of a typical arc of this type. It will be seen that the arc is of conical shape, the point of the cone being on the lower or negative electrode and spreading up to the upper or positive electrode. The arc consists of a central core of a pale bluish tint surrounded by an envelope of intensely white light and this in turn surrounded by another envelope which is yellowish but of relatively low luminosity. The cathode spot is very small and is in the center of a pool of molten oxides as may be readily seen from the photograph.

When it is remembered that the arc stream alone gives the light, it is at once seen that the mechanism of the lamp must be designed in an entirely different manner from that used with the carbon arcs where the electrode tips furnish a large proportion of the light. In the open and enclosed carbon arcs a slight change in the length of the arc made but little difference in the light; but in arcs of the magnetite type the intensity of the light emitted is roughly proportional to the length of the arc if other conditions are approximately constant so that in order to obtain a uniform intensity it is essential to keep the arc length fixed. How this has been accomplished in the design of the lamp mechanism may be understood from the following brief outline of the cycle of operation of this lamp. The magnetite electrode is lifted upward toward the copper upper electrode by means of a pair of clutches, the upper one lifting the holder and electrode and the lower adjusting the arc length, the amount of movement being limited by an adjustable stop. Fig. 2 shows the mechanism of one of these lamps. When the circuit is closed, the large starting magnet is energized lifting the lower electrode into forcible contact with the upper. When the current flows through the electrodes a small series cutout operates and opens the circuit through the starting magnet. This allows the lower electrode to slip down and draw the arc. The length of the arc is determined by the adjustable stop before referred to. The arc then operates at this fixed length until, due to the consumption of the electrode, the voltage across the arc momentarily rises to such a value that the shunt coil operates to close the contact and repeat the starting operation re-establishing the arc at the standard length. Since the surface of the lower electrode is melted while the arc is burning, it is necessary that the electrodes remain apart when the current is off, otherwise there would be danger of the electrodes freezing together.

The production of light from the magnetite arc is accompanied by the formation of metallic fumes which if permitted to condense on the globe would soon obstruct the light so that some means must be provided for removing these fumes from the vicinity of the arc. Since these hot vapors are naturally carried upward by convection currents

Fig. 2. Luminous Arc Lamp, Without Enclosing Casing and Glassware, Showing Mechanism and Electrodes

of air, a central chimney with the lower end surrounding the upper electrode serves as the simplest means of disposing of these fumes. This chimney, which also forms a central support for the lamp mechanism, provides sufficient draft so that variations in external air currents do not greatly affect the arc. As with most arcs, there is a considerable rectifying effect so that operation on alternating-current circuits is not practicable.

The negative electrode supplies the material for maintaining the arc and necessarily determines the efficiency of the entire unit. Much time and money have been spent upon the development of this electrode and the present commercial electrodes are the result of a vast number of experiments and painstaking work on the part of the laboratories. The name "magnetite arc" is derived from the fact that the common magnetic oxide of iron known as "magnetite" has been used as the base of this electrode. This material is particularly desirable for the purpose since it is a good electrical conductor at all times, is reasonable in cost and does not consume rapidly. On the other hand it gives off very little light of itself. After experimenting with a large number of metals and various compounds, it was found that titanium in some form would give a greater luminous efficiency than any other available material. The oxide or other form of titanium alone gives a very brilliant arc of excellent color but the fused oxide which is at once formed is non-conducting when cold, and the arc though bright is unsteady and the life short. A mixture of titanium oxide with magnetite together with a small amount of chromium oxide, which gives an added steadiness, produces an electrode that can be burned with excellent efficiency and at the same time is reliable and gives a reasonably long life.

In the manufacture of these electrodes the greatest attention must be given to the purity of the materials as a very small amount of impurity will seriously reduce the efficiency of the arc. The metallic ores as received from the mines are carefully crushed, cleaned by means of a magnetic separator, and then run over a water-table such as is used in mining work so that the resultant material shall be as pure as possible. Each lot is then carefully sampled and analytical tests made to determine its metallic content. The different ingredients are carefully weighed out and ground together in a ball mill to the degree of fineness that has been shown by experiment to give the best results. It is interesting to note that while the materials will pack well when the bulk of the material is at a certain degree of fineness, a greater compactness can be obtained when a certain proportion of it is somewhat coarser and the remainder somewhat finer, that is, the interstices can be filled better than when the material is all of the same fineness. In order to meet the varying demands of central stations, two standard mixtures have been developed and placed upon the market, known as the "long-life" and the "high-efficiency" electrodes. The high-efficiency electrodes give considerably more light than the long-life electrodes but consume more rapidly. Quite recently a new electrode has been made using the same compositions as the older electrodes but by the use of a tremendous pressure a considerably larger amount of material is compressed into the same space so that a longer life is obtained without sacrificing any of the luminous efficiency. These electrodes are made in various sizes and lengths for use with the different types of lamps.

The magnetite arc operates satisfactorily only on direct-current circuits. When these lamps were first put on the market they were operated on the old carbon-arc circuits from Brush arc generators; but later there was developed for their use a combined constant-current transformer and mercury-arc rectifier.

A point that should not be lost sight of in a lighting system is its reliability of operation. It is most essential that the lighting of streets be uninterrupted and the failure of any lamp to operate is a serious matter. The safety of the public may be greatly affected if lamps in certain sections are not burning. It is here that the luminous arc lamp presents another desirable feature. These lamps and electrodes have been developed to such a point that the central station can count with a high degree of accuracy on the life of the electrodes and arrange its trimming schedule so that electrodes will give their full life and at the same time not have any lamp burn out. The outage of the lamps for other reasons than burned out electrodes is very small. The total outage from all causes over a considerable period of time is frequently less than one fourth of one per cent.

The first type of luminous arc lamp was a pendant or suspended lamp operated on a 4-amp. circuit taking about 75 or 80 volts or 310 watts and with a life of about 200 hr. per trim. This type of lamp is still used in many cities and towns throughout the country. With the demand however for a large unit there was developed another lamp of similar design for operation on circuits of 6.6 amp. and taking about the same voltage as the 4-amp. lamp (75 to 80 volts; 528 watts). Later, an intermediate size was made for circuits of 5 amp.

About 1910 the first installation of ornamental luminous arc lamps was made in the city of New Haven, Conn. In this case the mechanism was placed beneath the arc instead of above, as in the case of the pendent type. The essential features of the mechanism how-

Fig. 3. State Street, Schenectady, N. Y., Illuminated by Ornamental Luminous Arc Lamps

Fig. 4. Fifth Avenue, Pittsburgh, Pa., Illuminated by Ornamental Luminous Arc Lamps Mounted on Trolly Poles

ever remain the same. The lower electrode is fed up against the copper upper electrode in the same manner, and the same arrangement of shunt and series cutouts is employed. The first lamp used a large one-piece globe of diffusing glass of distinctive shape. This form gave satisfactory results both as to its appearance by night and by day and also with regard to its efficiency. Later, several forms of sectional or panel-type globes were used to obtain more ornamental effects. Among these may be mentioned the spherical sectional globe designed for use on Pennsylvania Ave., Washington, D. C., and more recently the panel type such as is used in San Francisco's famous "Path of Gold" where the desired yellowish tone was obtained by the use of specially tinted glass panels.

The only parts to require regular renewal are the two electrodes, and of these the upper or copper electrode will burn from 2000 to 6000 hours depending upon the type and operating current so that the principal item of renewal is the lower electrode. Magnetite electrodes are made in large quantities so that, in spite of the extreme care necessary in their manufacture, their cost is low. The maintenance cost of these lamps is thus seen to be exceptionally low and this fact taken together with their high efficiency, unexcelled color of light, and remarkable reliability of operation has made and kept this type of lamp a most important factor in the lighting of American cities.

When so much is being said on all sides with regard to efficiency, it may be of interest to note that the luminous arc ranks very high in this respect. Without any equipment except a clear globe, the long-life electrodes produce from 11 to 18 lumens per watt and the high-efficiency electrodes from 17 to 25 lumens per watt. As with other illuminants there is an unavoidable loss in efficiency caused by the reflectors, refractors, and other equipment used for redirecting or diffusing the light.

As the arc burns, there is a slight motion of the arc across the electrode, unavoidable it may be said, but which may be considered an asset rather than a liability. There is not sufficient variation in the intensity to result in a flicker but just enough to give a sort of sparkle or animation to the light which only serves to improve the appearance of the installation.

Owing to the fact that the light is in the form of a long cone or pencil with its axis vertical the natural distribution of light is excellent, so that a smaller amount is lost in redirection than with the old carbon arc lamps where the electrode tips supplied the light. In those the maximum beam was redirected downwards at a small angle from the vertical and it was difficult to get a good distribution without excessive loss; but with the luminous arc the maximum intensity is at, or nearly at, the horizontal and it is only necessary to redirect the upward rays in order to get the most satisfactory results. With the ornamental lamps, however, even this is not done in many cases since it is desirable to obtain a good intensity on the building fronts. In high-grade city lighting of either the "white-way" or "intensive white-way" type, it is not sufficient merely to illuminate the surface of the road but considerable attention must be given to the general appearance of the street, building fronts, etc., if the best lighting results are to be obtained. The globes and equipment used with luminous arc lamps have been designed with this point carefully in mind. Globes of a large size in a single piece or made in sections of high-grade diffusing glass are used so as to obtain the desired distribution with a low intrinsic brilliancy.

Unique among commercial illuminants the luminous arc gives a white light. Upon careful test it is found to be a very close approximation to average daylight; a little warmer or more yellow than the light from a clear blue sky, a little colder or more blue than direct sunlight, and nearly the same in quality as the diffused light from white clouds on a pleasant day. Thus without any color correction an effect is obtained that is nearly the same as by daylight, and with the large secondary source of illumination used with the ornamental type of lamp there is produced a soft illumination that everywhere makes a distinctly pleasant impression and lends a particularly attractive appearance to a street lighted by luminous arc lamps.

Mazda Lamps for Street Lighting

By G. H. Stickney

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The Mazda lamp is playing a very important part in modern street lighting and many of the problems confronting the management of lighting companies involve matters discussed in this article. The author, after commenting on the steps leading up to the present high-efficiency Mazda C lamp, describes its essential features and characteristics. The questions of lamp rating, quality of light, depreciation in service, types of fixtures, etc., and their relation to satisfactory street lighting, are considered in detail. The operating characteristics of Mazda lamps on the standard types of series circuits is a question of vital importance to operating officials. The technical data relating to series Mazda C lamps is tabulated in convenient form for reference.—Editor.

Historically, the incandescent lamp for street lighting would naturally be considered with reference to three periods. The first is that preceding 1907, that is, before the advent of the tungsten filament. The carbon-filament lamps then used were relatively inefficient compared with the arc lamp, and were also at an economic disadvantage with the gas mantle lamp. Consequently, the principal use of the carbon-filament was limited to the occasional need for small sized lamps along arc lighting circuits.

The second period is that of the vacuum tungsten lamp, extending from 1907 to 1914. During this time the incandescent lamp came into extensive use in those classes of street lighting where small units were desired. While many of these lamps were used on the standard 6.6 and 7.5-amp. series circuits, the characteristics of this type of lamp favored lower current and some special series incandescent lamp circuits were established. The vacuum tungsten lamp however did not make much headway in those classes of lighting where large units were applicable.

Following the development of the Mazda C, or gas-filled tungsten lamp, which proved advantageous throughout the range of sizes required for street lighting, this type of lamp became the standard for most new installations and rapidly replaced the carbon-arc installations, which were then extensively used. The economy, flexibility, and convenience of the Mazda C lamp enabled it to assume the leadership in all classes of street lighting. Today, the Mazda C lamp admits but one competitor, namely, the magnetite arc, and that only in a limited field where high-power units are used.

It is with regard to the Mazda C lamp and this third period that our interest is at present centered.

Multiple and Series Lamps

Because of the inherent advantages of series arc lamps, practically all street lighting was established with series circuits. With the small sized Mazda lamps, the series type has some advantage with regard to efficiency. So far as the higher power lamps are concerned, there is little difference in the economy and effectiveness of the Mazda C series and multiple lamps. The choice, therefore, depends largely upon distribution and control problems.

Practically all the street lighting of Manhattan Borough and some of the white-way lighting in other cities employ multiple lamps. However, the series lamp is still the general standard for street lighting practice and will therefore be considered especially in this article.

Lumen *vs.* Candlepower Rating

Nearly all types of incandescent lamps which preceded the Mazda C lamp approximated the same ratio between the mean spherical and mean horizontal candlepowers. Their photometric curves were very similar and spherical reduction factors nearly identical.

Partly due to the coiling of the filament and partly to the various forms of filaments required for different sizes, the Mazda C lamp not only varied from its predecessors in respect to these candlepower relations but had different distributions for different sizes. Beyond this, lesser variations were encountered between individual lamps of the same identical class.

Owing to these conditions, practical lamp manufacturing required that the former practice of testing lamps for mean horizontal candlepower be discontinued, if a satisfactory product was to be turned out. Under the former condition, the mean horizontal candlepower had been a fair measure of lighting power, since it bore a fixed ratio to the mean spherical candlepower and therefore to the total lumens. (One mean spherical candlepower is equivalent to 12.57 lumens.)

While extreme variation in the distribution of light does affect the lighting value of a lamp, the total flux of light gives a much truer measure; and so long as the distribution does not vary beyond the limits so far encountered, there has seemed to be little choice, among the several distributions, so far as actual street illumination is concerned. The natural and fairest thing to do under these conditions would be to test and rate lamps in terms of lumens or mean spherical candlepower.

An obstacle to this practice was the existence of many long term street lighting contracts in which lamps were specified in mean horizontal candlepower, so that there was danger that a change in the method of rating would lead to misunderstandings between municipalities and central station companies. To meet this situation, an ingenious expedient was adopted. Since the lumen output of the Mazda B lamps was slightly less than ten times the mean horizontal candlepower, it was certainly fair to the purchasers of street lighting service to slightly increase the lumen output of the lamps and to test Mazda C lamps for a lumen output equal to ten times the rated candlepower. This was done and the rating retained as a nominal horizontal candlepower. In the long run, a nominal rating is not likely to be as satisfactory as one which indicates the actual performance for which equipment is built.

With this in view, and in the belief that sufficient time has elapsed to stabilize the situation, the lamp manufacturers have decided to rate lamps in lumens. For the present, the nominal candlepower will still appear in small type on the labels, but the ultimate plan is to drop the candlepower figures entirely. Under this arrangement, the 600-candlepower lamp is designated as a 6000-lumen lamp, the 400-candlepower lamp as a 4000-lumen, 100-candlepower as 1000 lumen, etc.

Color of Light

The light of an incandescent lamp contains a higher percentage of the red and yellow rays than does average daylight. It therefore has a slightly warm or yellow tint. Each advance in efficiency of incandescent lamps brings the light nearer to daylight in color value: the carbon filament light was whiter, if we may use the term, than a gas or oil flame light; the gem whiter than the carbon; the tantalum whiter than the gem; the Mazda B whiter than the tantalum; and the Mazda C whiter than the Mazda B. The present Mazda C lamp is still several steps away from daylight color value and there is a perceptible warmth or yellow tint in the light.

There has been some discussion as to what is the most desirable color of light for street lighting. So far as ability to see is concerned, there is no evidence that there is any choice between white and the warm tints. Taste is much more likely to be a deciding factor, and taste varies.

Some people express a preference for white light, while others are equipping Mazda C lamps with yellow tinted globes in the belief that an accentuation of the yellow tint is more pleasing. As an example of this, Mazda C lamps are now equipped with yellow globes on one of the most famous streets of the country, where a few years ago white light was considered a prime essential. Therefore, it seems fair to conclude that there is no reason for modifying the natural color of the light from the Mazda C lamp, except where decorative taste calls for a special effect.

Depreciation

All artificial illuminants are subject to depreciation of one sort or another, whereby there is a more or less gradual falling off in illumination due to decay of the light giving element, blackening of glassware, or accumulation of dirt on the outside.

Dust and dirt are carried in the air and will be accumulated wherever air currents penetrate. When these accumulations collect on transmitting glassware or reflecting surfaces, they result in loss of light from absorption. Periodic cleaning of all exposed lighting surfaces is necessary with Mazda lamps as well as any others. With large fixtures having sufficient radiation surfaces to insure proper cooling, it is sometimes advantageous to avoid internal ventilation and so reduce dirt accumulation.

The inherent depreciation of Mazda lamps comes from the slow volatilization of tungsten from the filament, and its condensation as a black deposit on the inner surface of the bulb. The reduction in cross section of the filament through this cause slightly increases the resistance, and on a constant-current series circuit this results in a slight tendency of a lamp to increase both in wattage and efficiency, and therefore in light output. On the other hand, the coating is a light absorber. Fortunately this coating forms more in the upper part of the Mazda C lamp, rather than opposite the filament, so that the absorption is less than might be expected. While this inherent depreciation may in some cases be as high as 20 per cent, it averages less than 10 per cent when the lamp has burned its natural life of 1350 hours. In fact, the most recent tests have shown practically no depreciation for this period.

There is of course no practical way of removing this bulb coating without destroying the lamp. The cure is the replacement of the lamp by a new one, and this should be done as soon as there is a noticeable blackening of the bulb opposite the filament. There will be individual lamps in which the blackening is faster or slower than normal. It is a good plan to inspect lamps periodically—for example when cleaning—and to replace all blackened lamps. Some companies make a practice of replacing all lamps after a certain period of burning, say 1500 hours. They have in this way not only maintained a high standard of lighting, but also have eliminated a large proportion of the outages. This is especially advantageous where the cost of making special trips to replace burned out lamps is high, or where there is a high penalty for outage of individual lamps.

The Mazda lamp probably runs more uniform as regards initial lumens (or candlepower) output, and depreciation through life, than any other artificial illuminant. Nevertheless there is a measurable variation between individual lamps, although the writer has never seen a case in which the variation in the illumination in the street could be observed without fairly accurate measuring instruments. It would therefore seem that further refinement to reduce such variation would not justify its cost.

If Mazda lamps are properly maintained, cleaned, and supplied with the prescribed amperage, they may be relied upon to deliver on the average the light claimed for them by the manufacturers. Beyond the foregoing factors the operator has no control over their output, although we occasionally encounter laymen who have an impression to the contrary.

Fixtures

The functions of a fixture are to support and protect the lamp, modify the light to meet particular needs, and provide ornamental appearance. The selection of the fixture has an important bearing on the effectiveness and efficiency of the light distribution. A variety of fixtures suited to the demands of different types of streets is available.

An enclosing fixture more or less retards the dissemination of heat. When only small sizes of lamps were available, any practicable fixture was almost certain to carry off the heat rapidly enough to maintain a satisfactory operating temperature. Following the advent of the high-power Mazda C lamps, there were developed some cheap fixtures of light-weight materials and small clearance spaces which caused some cases of overheating. Now-a-days, such fixtures are seldom found.

We do occasionally encounter fixtures in which the ventilation arrangements are not such as to exclude rain or snow. The lamp bulb runs warmer when enclosed, and is therefore more susceptible to breakage from cold water falling upon it. There have been a number of complaints as to the performance of Mazda C lamps where it was found that the failure was due to water entering the fixtures and falling on the bulb. Three ways of overcoming this trouble are as follows:

(1) If the fixture is large and provided with sufficient radiating surface to avoid overheating, the ventilation openings may be omitted or stopped up. This has the further advantage of preventing the accumulation of dust on the interior of the fixture. In this connection, it may be mentioned that some fixtures have been tested in which the so-called ventilating openings were not arranged so as to produce a current of air through the fixture, and therefore did not serve to cool the lamp.

(2) Arrange ventilating openings so as to effectively prevent entrance of snow or rain. It is practically impossible to prevent entrance of moisture in the form of fog or mist, so that this provision may not be entirely effective in certain locations.

(3) Arrange the interior of the fixture so that any water entering or condensing on the walls of the fixture will fall clear of the lamp. Drip points directly above the lamp should be avoided, or a shield similar to an umbrella may be suspended beneath them. The umbrella shield has been found effective in correcting the trouble in improperly designed fixtures.

Straight Series *vs.* Compensator Lamps

The lower power Mazda lamps are made for operation directly in series on the line current, usually 6.6 amp. The 15,000-lumen (1500-c.p.) lamp is made for 20-amp. operation only; the 4000-lumen (400-c.p.) lamps are made for both 6.6 or 15 amp.; the 6000-lumen (600-c.p.) and 10,000-lumen (1000-c.p.) lamps are made for 6.6 or 20 amp.

The 15 or 20-amp. lamps are usually operated from 6.6-amp. circuits, but the current through the lamp is stepped up to the rated value by means of a transformer or compensator (auto-transformer). The choice in this connection almost invariably resolves itself into a question of economy and installation requirements.

The high-current lamps are more efficient and so even with transforming losses consume less wattage than the corresponding straight series lamps. On the other hand, the transformer or compensator means additional initial investment.

Some question has occasionally been raised as to the relative color of light from the straight-series and compensator-type lamps. The light from the latter is presumably slightly nearer to white in color, but the difference is so slight that it is doubtful if an observer can distinguish it, even by simultaneous contrast.

Compensator lamps are not recommended for use with compensators supplied directly from constant-potential circuits. Under this condition they are liable to an excessive variation in efficiency and life, with the possibility of other complications. Cost analyses indicate no economic gain over straight multiple lamps, which have other points of advantage.

Series Lamps for Street Lighting

The standard series Mazda lamps are listed in Table I, which also gives principal dimensions and other data. The standard amperage for series circuits is 6.6, and there are but very few circuits now in use which do not conform to this practice. The high-current lamps are of course for use in connection with transformers or compensators.

Under present conditions, the use of lamps of less than 1000 lumens is seldom justified. In these sizes, the overhead forms so large a part of the cost of service that any saving possible, through the use of smaller lamps, is exceedingly small. It is therefore good business to secure the greater effectiveness of the larger lamp.

Illuminating engineers who have given close attention to street lighting problems have persistently recommended the use of larger lamps in all classes of street lighting. This recommendation is based on experience in producing effective results and on the economic considerations.

A 15,000-lumen (1500-c.p.) lamp has therefore been recently added to the list, and a 25,000-lumen lamp indicated as the next step to be taken as soon as the demand is sufficient to warrant it. An analysis of costs in conjunction with an observation of street lighting effects is almost certain to indicate the desirability, on the part of almost any community, of providing higher power lamps than those now used.

Lamps for Rectifier Circuits

It is sometimes desirable to operate Mazda lamps in series with luminous-arc lamps on

TABLE 1

TECHNICAL DATA ON STANDARD MAZDA C LAMPS FOR SERIES STREET LIGHTING SERVICE

Rated Initial Lumens	Mean Lumens P'r C'nt of Aver. Initial Lumens	Rated Initial Lumens per Watt	Mean Lumens Per Watt	Hours Life	Average Volts	Average Watts	Bulb	Screw Base	Max Overall Length, Inches	Light Center Length, Inches	Position of Burning	Std. Pkg. Qty.	List Price Clear
MAZDA C LAMPS—6.6 AMPERES													
600	100	12.2	12.2	1350	7.4	49.2	S-$24\frac{1}{2}$	Mogul	$7\frac{1}{4}$	$5\frac{3}{8}$	Any	48	$1.00
800	100	13.2	13.2	1350	9.2	60.6	S-$24\frac{1}{2}$	Mogul	$7\frac{1}{4}$	$5\frac{3}{8}$	Any	48	1.20
1000	100	14.0	14.0	1350	10.8	71.4	S-$24\frac{1}{2}$	Mogul	$7\frac{1}{4}$	$5\frac{3}{8}$	Any	48	1.20
2500	100	15.7	15.7	1350	24.1	159.0	PS-35	Mogul	$9\frac{3}{4}$	7	Any	24	2.35
4000	100	16.1	16.1	1350	37.6	248.0	PS-35	Mogul	$9\frac{3}{4}$	7	Any	24	4.00
6000	100	16.1	16.1	1350	56.4	372.0	PS-40	Mogul	10	7	Any	12	5.00
MAZDA C LAMPS—15 AMPERES													
4000	100	17.9	17.9	1350	14.9	223.0	PS-40	Mogul	$12\frac{1}{2}$	*$9\frac{1}{2}$	Tipdown	12	$4.00
MAZDA C LAMPS—20 AMPERES													
6000	100	19.3	19.3	1350	15.5	310.0	PS-40	Mogul	$12\frac{1}{2}$	*$9\frac{1}{2}$	Tipdown	12	$5.00
10000	100	19.3	19.3	1350	25.9	518.0	PS-40	Mogul	$12\frac{1}{2}$	*$9\frac{1}{2}$	Tipdown	12	6.00
15000		19.9		1350	37.6	753.0	PS-40	Mogul	$12\frac{1}{2}$	*$9\frac{1}{2}$	Tipdown	12	7.00

* This lamp, if made for tip-up burning, has a light center length of $8\frac{1}{4}$ inches.

direct-current series circuits, supplied from constant-current transformers and rectifiers.

It has been found that the ammeters generally used in such circuits do not give the correct measure of the heating power of the current as transmitted to the lamp filament. In other words, when a regular 6.6-amp. series Mazda lamp is operated on a rectifier circuit, if the ammeter indicates 6.6 amp., the lamp will give more than rated light, consume more than the designated watts, and will have a shorter life than normal.

To meet this situation, special rectifier lamps are provided which give proper performance on such circuits. The series rectifier lamp has to meet another peculiar condition whereby the gas-filled lamp is occasionally subject to the formation and maintenance of an internal arc which may injure the socket of a fixture. This does not occur with the vacuum construction, so that it is the practice of the lamp manufacturers to recommend Mazda B lamps for series rectifier service.

While it is true that many operators have not encountered this difficulty, it is generally better practice to follow the recommendation. Devices have been developed which seem to prevent arcing trouble, but so far have not proven very popular as the problem has not generally been considered of sufficient importance to warrant the expenditure.

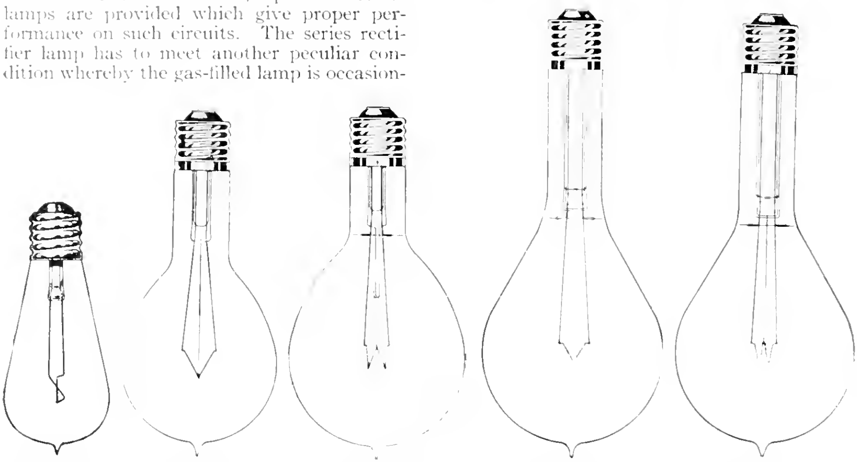

Fig. 1. Bulb Sizes and Construction of Standard Mazda C Lamps for Series Street Lighting Service

Cost as a Factor in Lamp Selection

There seems to be a popular assumption that the cost of street lighting is approximately proportional to the size of the unit. In all the instances in which the writer has figured such costs, it has been evident that the costs run up very much slower than the proportional rate.

In the first place, considerably over half the cost of the service falls in what is commonly called overhead, including such items as result from investment in fixtures, poles, lines, transforming equipment, etc. It is obvious that these items do not increase in proportion to the increased size of lamp. In fact, it is often possible to increase the size of the lamp without any increase at all in some of these items.

The labor of cleaning the lamp and equipment is almost independent of the size. Also, a good share of the trimmer's time is taken in going from one lamp to another.

Referring to Table I, it will be noted that the higher power lamps are generally more efficient than the smaller sizes, and that the current consumption does not go up so fast as the lumens (or candlepower). Likewise lamp costs are not in proportion to the lighting power (lumens).

For example, note the following comparisons:

Size of lamp in lumens	1000	800	600
Size of lamp nominal candlepower	100	80	60
Relative lighting power	100	80	60
Relative watts	100	85	69
Relative lamp cost	100	100	83.3

Size of lamp in lumens	15000	10000	6000
Size of lamp nominal candlepower	1500	1000	600
Relative lighting power	100	66.7	40
Relative watts	100	68.6	41
Relative lamp cost	100	85.6	71.2

For specific cases, these comparisons should be expanded to include the various items of overhead, as based on actual operating conditions. Where comparisons are made for the purpose of determining the size of lamp for a given spacing, the problem is comparatively simple. Where variations of spacing are involved, the question of distribution enters and introduces other factors of street lighting design, somewhat beyond the scope of the present discussion.

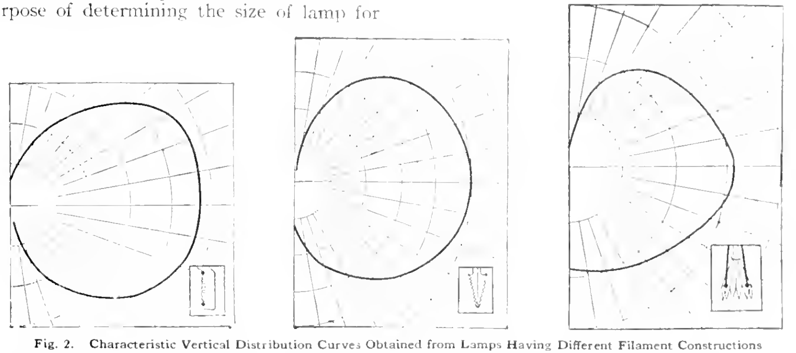

Fig. 2. Characteristic Vertical Distribution Curves Obtained from Lamps Having Different Filament Constructions

Position of Burning and Importance of Filament Position in Accessory

Some of the smaller sizes of Mazda C lamps are manufactured so that they give equally good service in either the tip-down or tip-up position. The larger sizes however are manufactured to burn in either one or the other position, depending upon the service for which they are intended. The large Mazda C lamps are regularly made for burning in a pendant or tip-down position. Where the fixture construction is such that the lamp operates in a tip-up position, tip-up lamps should be used so as to insure satisfactory operation. Universal lamps, which can be operated in any position, could have been made standard but the better quality and efficiency of the present constructions justified the limitations.

In fixtures which employ prismatic glass refractors, the position of the lamp filament with regard to these accessories is of extreme importance. Lamps are manufactured with filament positions as near to a definite location within the bulb as is practicable. Fixtures utilizing prismatic glassware are designed to accommodate lamps of a definite light-center length.

It should be borne in mind that when a change is made in the size of lamp utilizing the same fixture, proqision should be made for any change in light-center length between the old and new lamp, otherwise unsatisfactory distribution of light may result.

Prismatic refractors for street lighting are so designed that the maximum candlepower is approximately 10 deg. (sometimes 15 deg. below the horizontal. A change in filament position in these refractors quite materially changes the distribution of light. One-quarter inch variation from the normal position of the filament will change the position of maximum candlepower approximately 10 deg. From this it may be seen that such a variation would qvite materially affect the distribution of light. With other types of reflectors and glassware, slight variations do not materially affect the distribution of light. However, it is strongly recommended that care be exercised in this respect, inasmuch as the most desirable distribution results when filaments are located in their proper position with respect to the reflector or glassware.

Street Lighting Glassware

By S. L. E. Rose

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One of the most important parts of a lighting unit is the glassware. To obtain certain desired effects the proper type of globe must be used. The following article furnishes comparative data on the different types of modern globes available for street lighting. In addition to the effect of the globe on the efficiency of the unit, the author points out other important factors to be considered in selecting the glassware for a modern installation.—Editor.

It is self evident that we can never get more light from a unit than is given by the lamp used in the unit. In fact, adding equipment such as reflectors, refractors, globes, etc. always reduces the total lumens given by the unit.

The efficiency of a lamp is expressed in lumens per watt.

The efficiency of a complete unit, however, is usually expressed as per cent of bare lamp lumens and is obtained by dividing the total lumens of the unit by the total lumens of the lamp. Thus, if the lamp gives 1000 lumens and the complete unit gives 800 lumens, the efficiency of the unit is 80 per cent.

The efficiency is affected by the type of fixture used, the size of reflector, and the nature of the reflecting surface as well as the thickness and density of the glassware. As each piece of equipment is added some of the light from the lamp is lost. It should be noted, however, that an internal reflector in some units will increase the light from the unit as a whole by decreasing the loss in the housing or metal canopy.

If the efficiency of the unit were the only consideration we would use bare lamps to light our streets but other factors enter into the problem, such as the necessity of protecting the lamp from rain and snow, average intensity on the street surface and midway between units, glare, appearance, etc., which make it necessary to use accessories in order to get the best results.

We must sacrifice some of the light from the lamp in order to get certain desired results; in other words, we must lose some light from the lamp in order to increase the utilization efficiency or increase the aesthetic value. In fixtures using paneled globes, shown in Figs. 1 and 2, the loss is greater than where a one-piece globe is used, due to the frame and ribs that form the panels. The ornamental feature is of primary importance here and efficiency of secondary consideration.

If we change from a small reflector to a larger one, from clear glass to diffusing glass, or from light density glass through which the light source is visible to a denser glass which conceals the source and gives better diffusion, we must lose some light, but if by the change we can accomplish the purpose we are striving for, then the loss is justified and compensated for by the superior results obtained.

From the foregoing remarks it is seen that the total loss in a lighting unit is made up of the sum of the losses in the various parts that compose it.

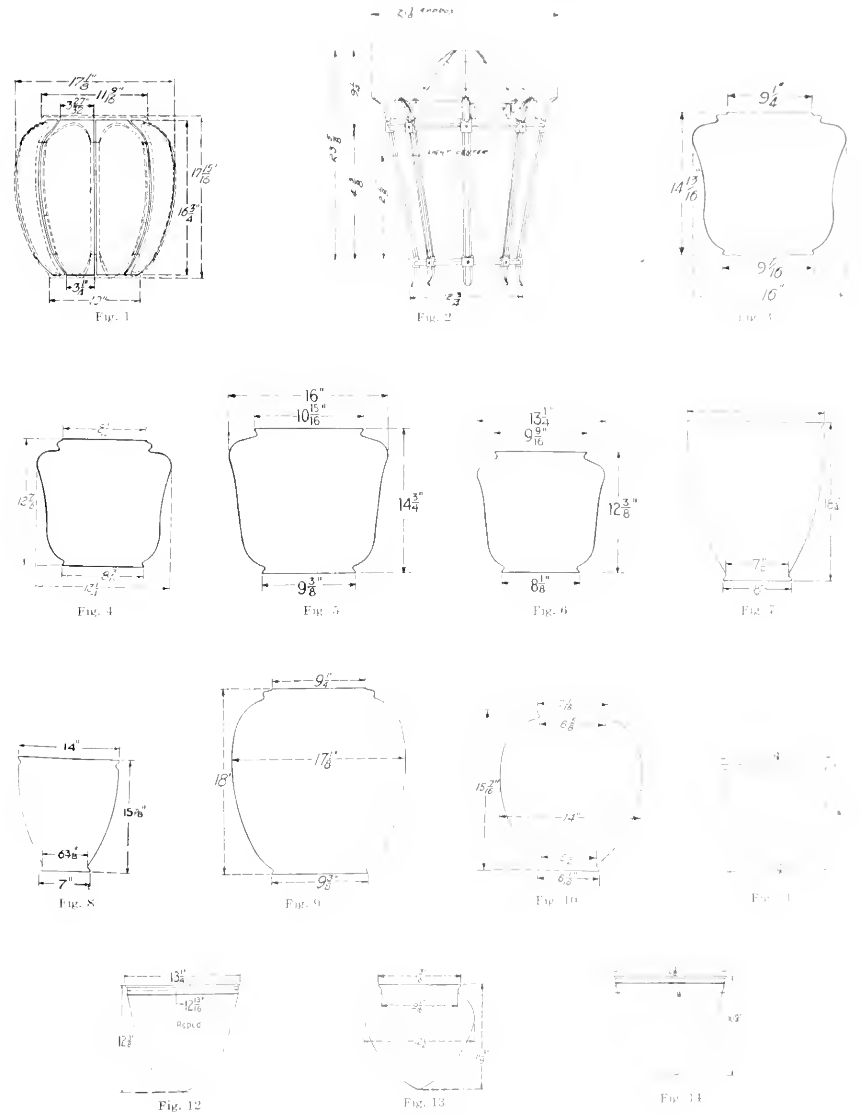
There are various kinds of glass used for globes and each kind may be obtained in different weights or densities. These are usually marketed under trade names which convey no clear idea of the quality or appearance of the glass.

Certain types of globes from the same manufacturer and supposedly of the same kind may vary in light transmission due to varying thickness and density, which it is apparently difficult to eliminate altogether. Some of the factors influencing the transmission are the shape of globe, thickness of glass, density of diffusing media used in their manufacture, as well as the personal element that enters into their manufacture.

In comparing globes of different makes, where only one sample of each kind is tested, it is well to remember the influencing factors for glass manufacturers can vary the density within quite wide limits.

When selecting glassware, therefore, in addition to the transmission, other factors should be taken into consideration, such as general appearance of the unit when lighted and when out, also the ability to withstand handling and weather conditions met in practice.

With the older types of glass, such as opal, alabaster, carrara, and alba, the light source was visible and good diffusion could be obtained only by sacrificing transmission. With the newer glass, such as genco, the light source is not visible and good diffusion is obtained as well as high transmission and light weight. With rippled glass the light



Figs. 1 to 14. Modern Types of Globes for Street Lighting source is not visible and high transmission is secured.

In discussing globes they are usually spoken of as clear, light density, medium density, heavy density, etc., depending on their transmission. It is very difficult to draw any definite line between these different densities; i.e., where "light density" shall end and "medium density" begin, owing to a lack of standardization, for what one glass manufacturer would call light another would call medium and vice versa; it being merely a matter of degree with each manufacturer and depends on his point of view.

Experience has taught that a globe which is satisfactory for a luminous arc lamp may not be at all satisfactory when used with an incandescent lamp and vice versa.

If it is desirable to use a refractor and at the same time conceal it from view, a diffusing globe cannot be used as it would nullify the distribution of light which a refractor gives.

It has been necessary, therefore, to make globes from various types of glass in order to obtain the different effects desired.

One of the latest developments consists of globes of clear rippled glass having different finishes such as acid etching, a light flashing of opal or alabaster glass. Globes of this type will conceal the lamp and refractor and give brilliancy and snap to the light from an incandescent lamp.

TABLE I

LIGHT TRANSMISSION LOSS IN GLOBES

Type of Globe	Kind of Glass	Density Rating	Weight Lb.	Weight Oz.	Per Cent Loss
Fig. 11	Crystal	Clear	6	7	3.6
Fig. 11	Carrara	Light	6	9	17.8
Fig. 12	Rippled	Clear	4	12	10.3
Fig. 12	Rippled	R.I. & R.O.	5	6	25.5
Fig. 13	Crystal	Clear	4	8	4.2
Fig. 13	Carrara	Light	3	9	19.6
Fig. 14	Rippled	Clear	3	13	13.8
Fig. 4	Genco	Light	4	12	22.2
Fig. 6	Rippled	Clear	6	7	8.5
Fig. 6	Rippled	R.I. & R.O.	6	11	22.3
Fig. 3	Crystal	Clear	10	8	9.1
Fig. 3	Alba	Light	10	12	19.0
Fig. 3	Carrara	Light	11	4	17.9
Fig. 3	Carrara	Medium	12	12	31.2
Fig. 3	Alabaster	Light	9	8	17.9
Fig. 3	Alabaster	Medium	10	0	27.9
Fig. 3	Polycase	Medium	11	4	28.8
Fig. 3	Monax	Light	4	12	22.2
Fig. 3	Genco	Light	4	14	23.9
Fig. 5	Rippled	Clear	11	9	8.7

The arbitrary limits fixed by the photometric division of the Illuminating Engineering Laboratory for classifying globes used in Novalux units and luminous arcs, in reference to their density and transmission or loss, are given in Table II.

TABLE II

Designation	Per Cent Transmission	Per Cent Loss
Clear	90 or more	10 or less
Very light density	85 to 90	15 to 10
Light density	75 to 85	25 to 15
Medium density	60 to 75	40 to 25
Heavy density	50 to 60	50 to 40
Very dense	50 or less	50 or more

Brightness, which is commonly expressed in candlepower per square inch, is an important factor in selecting the proper globe for various purposes. It should be borne in mind that with the same lamp a small globe will appear brighter than a large globe while the same amount of light may be transmitted. When lamps of low candlepower are used they should be equipped with smaller globes than where high candle power lamps are used, otherwise the effect may be disappointing.

For this reason globes of the same shape have been developed in various sizes, such as those shown in Figs. 3 and 4, 5 and 6, 7 and 8, and 9 and 10. In general, it may be stated that the smaller globes should be used for lamps of 400 c-p. or less and the larger globes for 600 c-p. or more.

When a clear glass globe has its surface roughened or depolished, either by sand blasting or acid etching, it is spoken of as crystal

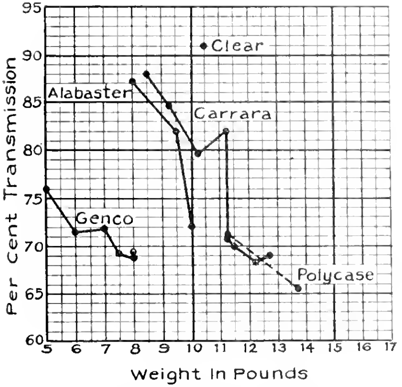


Fig. 15. Illustration of the Effect of the Thickness of the Glass of Globes Upon Light Transmission. The curves refer specifically to the type and size of globe shown in Fig. 3

roughed inside, crystal roughed outside, crystal roughed inside and outside, depending on whether the inner, outer, or both surfaces are roughened. These terms are usually abbreviated to C.R.I., C.R.O., C.R.I. and R.O.

If other than a clear glass globe is roughened, the term "crystal" or the letter "C" is omitted from the designation. In general, acid etching gives a smoother finish than sand-blasting, and for this reason a light acid etched finish is sometimes called "velvet finish" (V.F.) or "satin finish" (S.F.).

This treatment increases the diffusion but also increases the loss. A comparison of various kinds of glassware is given in Table I. The per cent loss given is for the glassware only, the light from the unit without the glassware being taken as 100 per cent. The efficiency of complete units with globes listed in Table I will vary from 60 to 80 per cent depending on the type of fixture and density of glassware.

With few if any exceptions, the loss of light in a globe is proportional to the weight, or we may say the transmission of a globe is inversely proportional to its weight. This is illustrated by the curves in Fig. 15 which are prepared for the Fig. 3 type of globe made of different kinds of glass available at the present time. Investigations now under way indicate that the weight of Genco globes may be increased to give the necessary mechanical strength for street lighting service without reducing their high transmission factor.

Ideal globes for street lighting are those which have high transmission factors with proper diffusion to obtain the results desired without sacrificing mechanical strength. While a comparison of globes on a basis of transmission efficiencies is necessary and desirable, it should be remembered that this is only one factor to be considered in the choice of a street lighting unit. In the final analysis, the elements composing a street lighting system may be considered 100 per cent efficient when the system as a whole gives 100 per cent satisfaction.

Series Lighting Transformers

By T. Whyte

Transformer Department, General Electric Company

This article presents a synopsis of the available range of transformers for series street lighting service. The author introduces his subject by a discussion of the fundamental principles underlying the operation of constant-current transformers. The equipments for the two modern systems of street lighting, namely, the luminous arc system and the Mazda system, are described and the various types of transformers for indoor, outdoor, and pole service are explained.—Editor.

In considering the subject of transformers for the operation of series lamps requiring constant alternating current, or direct current through rectification, the object of this article is not to expound the theoretical values or characteristics of design but rather to define the various types of transformers standardized for this work, and to outline as briefly as possible their respective applications and theory of operation.

Since the advent of series lighting, manufacturers of electrical apparatus have produced various types of transformers and regulators designed to maintain constant current on the secondary, but the only transformer at present in use which actually will deliver and maintain constant current on all loads regardless of fluctuations in supply voltage and frequency is the moving-coil regulating transformer.

This type of transformer is designed on the theory that a constant series reactance will maintain approximately constant current provided the circuit is highly inductive. In order to keep the power-factor of the system within reasonable limits, however, it is necessary to arrange this reactance so that it will change with the load in such a manner as to keep the total impedance and consequently the current at a constant value. This variable reactance is obtained in the moving-coil regulating transformer by means of two coils movable with respect to each other on a common core.

In all constant-current transformers manufactured by the General Electric Company, whether for alternating-current lighting or direct-current lighting through rectification, one coil is stationary while the other is movable and mechanically connected to a rocker arm, to the other end of which weights are attached. These weights together with the magnetic repulsion between coils counterbalance the weight of the moving coil. At full load the moving coil is floating immediately above the stationary coil, and as the load falls off the tendency for the current to rise is offset by the separation of the coils. This separation is caused by the greater repulsion of the increased magnetic flux due to the momentarily increased current in the secondary coil. With the coils farther apart, more of the magnetic lines of force from the primary coil go out between the coils as leakage flux and the electromotive force induced in the secondary is decreased in proportion to the fall in the secondary load, thus maintaining the secondary or load current at a constant value.

All other devices at present on the market, including high-fixed-reactance transformers, do not maintain constant current when the load varies but are designed to deliver a definite current at a definite load, and any variation of the load or any variation of impressed voltage or frequency will cause a change in secondary current, the magnitude of this change depending upon the change in the load and the reactance of the transformer. The better a device of this kind takes care of secondary changes, the more it magnifies the effect of primary fluctuations.

From a theoretical point of view, the moving-coil regulating transformer is the only device which actually will maintain constant current on all loads, and can therefore be justly termed a "constant-current transformer."

The requirements of the different classes of municipal lighting are successfully met today by two systems of street lighting. These are the luminous arc lamp system and the incandescent lamp system, and as each system requires a particular transformer application, they must necessarily be considered separately.

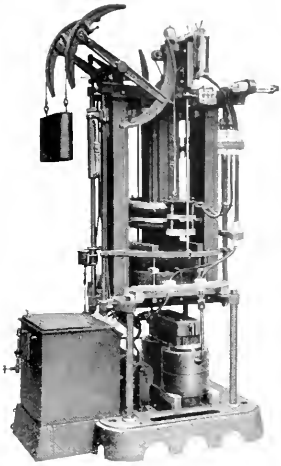


Fig. 1. Mercury Arc Rectifier Outfit for Series Luminous Arc Lighting (Interior View)

Fig. 2. Rectifier Tank Showing Tube Carriers and Water Cooling Coils

Series Luminous Arc Circuits

The series luminous arc lamp requires direct current for its operation and since it has been the general tendency of central stations to get away from motor-generator sets or belted arc machines, it became necessary to devise means for obtaining a unidirectional series current direct from an alternating-current source of supply. The result of exhaustive investigations has been the development of a series mercury-arc rectifier outfit consisting of a constant-current transformer, direct-current reactance, rectifier tube, rectifier-tube tank, static protector, exciting transformer, static discharger, and in some special cases additional automatic devices to eliminate, as far as possible, the attention of an operator and to insure approximately uninterrupted service.

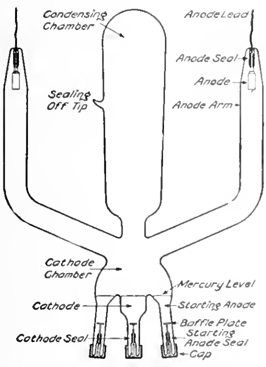


Fig. 3. Glass Tube for Rectification

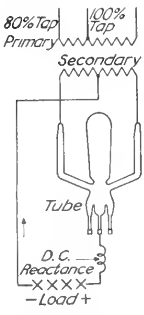


Fig. 4. T ansformer and Rectifier Connections for Single-Tube Operations

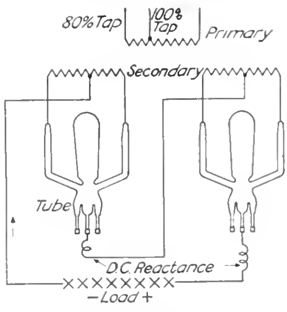


Fig. 5. Transformer and Rectifier Connections for Two-tubes in-series Operation

This type of outfit is essentially for indoor installation and is designed to transform constant-potential alternating current into constant direct current by means of the constant-current transformer and the rectifier proper, in which the process of rectification

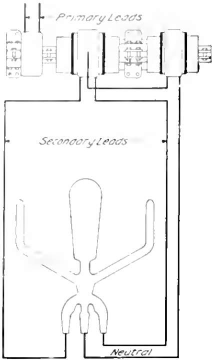


Fig. 6. Exciting Transformer Connections to Rectifier

takes place. This rectification is made possible by the well-known property of ionized mercury vapor, which allows the passage of current in one direction only. When the negative mercury electrode is in an active state, as for instance when the arc is operating, only a few volts are necessary to maintain the arc in one direction, but the voltage must be extremely high to maintain an arc of reversed polarity, that is, for practical purposes the ionized vapor is a good conductor of current in one direction and an insulator in the other.

A cathode or negative working electrode is connected through the direct-current load and the direct-current reactance to the middle of the constant-current transformer secondary winding. The working anodes are connected to the outer terminals of the secondary. When either anode is positive, there is an arc which carries current between it and the cathode. When the polarity of the alternating-current line reverses, the arc passes from the other anode to the cathode, the two anodes alternately acting as the positive terminal of the tube in accordance with the alternating polarity of the secondary. Hence, during the complete cycle the cathode is negative and the current at this point is uni-directional. It will be seen from the foregoing that each half of the alternating current is used, this fact being responsible for the high efficiency of the luminous arc system.

The initial ionization of the mercury vapor is accomplished by first establishing an arc between the two auxiliary anodes and the cathode, the anodes for this purpose being connected to a low-potential alternating-current supply through a small low-potential exciting transformer, and connected as for a multiple rectifier operating on short circuit. This starting arc is established by the bridging and subsequent breaking of the mercury bridge between the cathode and the start-

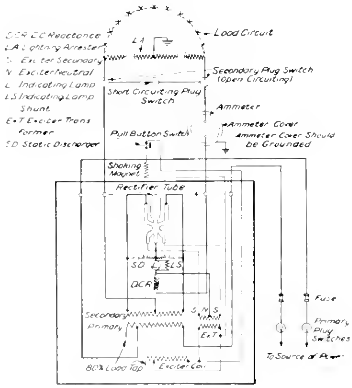


Fig. 7. Connection Diagram of Single-tube Rectifier Outfit

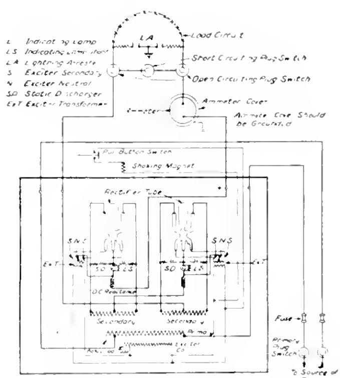


Fig. 8. Connection Diagram of Rectifier Outfit with Two Tubes in Series

ing anodes, when the tube is given a slight shake.

When this starting arc is established, the main load switches may be opened which automatically applies the high potential of the load circuit to the main anodes and the rectification of the current immediately commences.

A complete line of series lighting mercury-arc rectifier outfits has been standardized in capacities of 6, 12, 25, 50, 75 and 100 lamps for operation on alternating-current supply circuits of any commercial voltage and frequency and for luminous lamps of 4, 5, or 6.6-amp. normal current rating. The main outfit is air-cooled but the rectifier glass tube, in which rectification takes place, is oil immersed and maintained at a normal temperature by means of water cooling coils within the tube tank.

The smaller capacity outfits are designed to operate with only one rectifier tube but the larger capacity outfits are arranged to operate with two tubes in series which increases the reliability of operation and results in a very much higher average tube life.

Series Incandescent Circuits

The design of constant-current transformers used for series incandescent lighting is the same as the transformer component of the rectifier outfit, but on account of the extremely sensitive nature of the filament used in gas-filled high-efficiency lamps, the operation and regulation of the transformer must be correspondingly sensitive and must of necessity be designed with this object in view.

Two distinct types of transformers have been developed for this service, which although designed on the same theory of operation are very different in mechanical construction, one type being air-cooled and for indoor installation, while the other is designed to operate outdoors and is oil-cooled and partially oil-insulated.

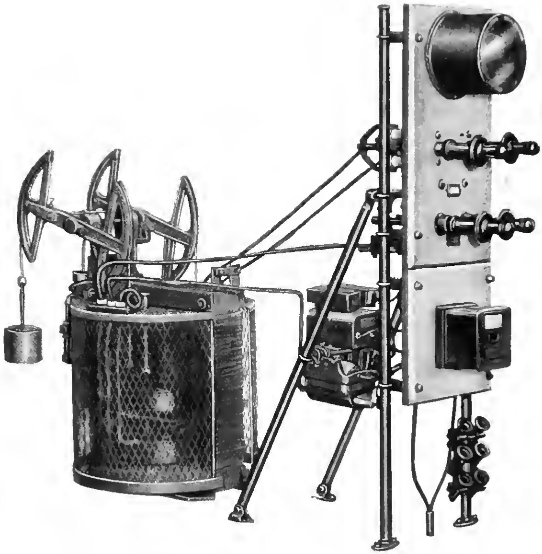


Fig. 9. Indoor Constant-current Transformer with Panel

The indoor or station type transformer represents the results of a very careful study made to determine the actual inherent requirements of a modern series incandescent load and to arrive at constants to be used in design which would assist in the production of a transformer at reasonable cost, rugged and simple construction, and possessing all the characteristics essential to the satisfactory operation of a load of this nature.

Practically all friction has been eliminated in this type of transformer by the use of ball bearings in the balancing mechanism, and

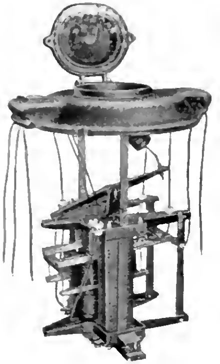


Fig. 10. Internal View of Outdoor Constant-current Transformer

this together with high repulsion between coils which is a special feature of this design insures almost perfect regulation on varying loads, and a dashpot is provided to steady the action of the moving elements caused by fluctuations in voltage and frequency in the supply circuit and swinging "grounds" often prevalent in overhead lighting circuits. Table I gives data on 60-cycle 2300-volt-primary indoor constant-current transformers of this type for 6.6-amp. alternating-current series lighting circuits. With minor changes in design, these transformers can be arranged for operation on supply circuits of any commercial voltage and frequency and for all standard series lamps.

Outdoor Constant-current Transformers

Considerable difficulty has been experienced in the past in solving the demand for higher intensities and lighting units in the suburbs of large cities, the growth of these outlying districts being so rapid that it has been almost impossible to keep pace. When it becomes impracticable to run circuits from the central station on account of the distance and copper required, it is not always advisable to erect a substation. At any rate, the growth is usually so rapid that during the interval before the substation can be erected the lighting service is likely to be inefficient or ineffectual.

Lighting systems requiring constant-current transformers have hitherto been in proximity to a central or substation where the transformer could be installed. On account of smaller towns and villages not being able to derive sufficient revenue to warrant the installation of a substation and attendant, the problem placed before the transformer engineers was to design and produce a satisfactory constant-current transformer for outdoor installation.

This required considerable research work as a transformer of this kind must not only possess all the inherent characteristics of an indoor transformer, but must also be entirely automatic in action and be designed and manufactured to compare in cost with any of the so-called constant-current devices on the market. As a result of this research work, there has been developed and standardized a

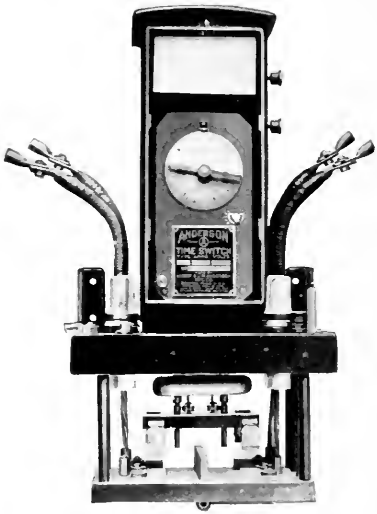


Fig. 11. Automatic Time Switch Electrically Wound for Use with Outdoor Constant-current Transformer

complete line of constant-current transformers which admirably fills this demand. This type of transformer is positive in action and is controlled by a time switch which insures absolute precision in energizing and de-energizing the load circuits at predetermined times.

The outdoor transformer has been developed primarily for the operation of modern Mazda lamps, and is designed to maintain the secondary current at normal rating on all loads from full to short circuit, and to protect the lamp circuit at the moment of starting and during operation from an instantaneous rush of excessive current and mercial voltage and frequency and for all standard series lamps.

Certain classes of street lighting require lower potential than that usually obtainable from the ordinary constant-current series circuit, and to provide for this, lighting companies would be compelled to run multiple circuits from the central station often at a

TABLE I

KW. OUTPUT	WT. IN NET LB.	EFFICIENCIES Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	PRIMARY POWER-FACTORS Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	DIMENSIONS IN INCHES A	B	C
5	300	95.0	94.25	91.5	90.0	83.75	56.25	34	17	23
10	475	95.25	95.0	92.25	90.75	84.25	56.75	37	20	25
15	650	95.5	95.35	93.0	91.0	84.75	57.0	40	23	28
20	800	95.75	95.5	93.75	91.5	85.25	57.25	44	25	30
25	1050	96.0	95.75	94.5	91.75	85.75	57.50	48	27	34
30	1250	96.25	96.0	95.0	92.0	86.0	57.75	53	28	38
40	1350	96.5	96.25	95.25	92.0	86.0	57.75	55	30	42
50	1550	96.5	96.25	95.25	92.25	86.25	56.0	57	31	43
60	1800	96.75	96.5	95.5	92.25	86.25	56.0	59	34	45
70	2100	96.75	96.5	95.75	92.25	86.25	56.0	63	36	47

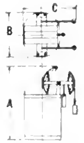
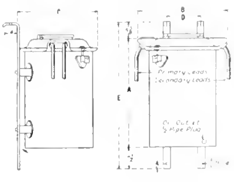


TABLE II

Kw. Output (At Unity P-F. Load)	Primary Amp.	Trans Kv-a. Input	Secondary Load Volts	EFFICIENCIES Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	$\frac{1}{4}$ Load	PRIMARY POWER-FACTORS Full Load	$\frac{3}{4}$ Load	$\frac{1}{2}$ Load	$\frac{1}{4}$ Load
1.0	0.68	1.57	152	91.5	89.5	85.0	73.0	70	51	36	20
2.0	1.34	3.08	303	93.0	91.0	87.0	77.0	70	51	36	20
3.0	1.99	4.58	455	93.5	91.5	88.0	78.5	70	51	36	20
5.0	3.31	7.62	758	94.0	92.1	89.0	80.0	70	51	36	20
7.5	4.94	11.37	1136	94.5	92.7	90.0	82.0	70	51	36	20
10.0	6.55	15.05	1515	95.0	93.5	91.0	83.5	70	51	36	20
15.0	9.65	22.2	2270	95.0	93.5	91.0	83.5	70	51	36	20
20.0	12.95	29.8	3035	95.0	93.5	91.0	83.5	70	51	36	20

Kw. Output (At Unity P-F. Load)	Oil Gal.	Net Wt. in Lb. Including Oil (Approx.)	DIMEN. IN INCHES (APPROX.) A	B	C	D	E
1.0	25	400	30	21	20	9	44
2.0	35	550	35	26	22	10	48
3.0	35	600	35	26	25	10	48
5.0	40	700	35	29	25	$11\frac{1}{2}$	48
7.5	40	725	35	29	25	$11\frac{1}{2}$	48
10.0	40	750	35	29	25	$11\frac{1}{2}$	48
15.0	60	1775	41	32	28	13	54
20.0	60	1875	41	32	28	13	54



from other surges and fluctuations on the line which would tend to destroy or shorten the life of the lamps. Table II gives data on 60-cycle 2300-volt-primary outdoor constant-current transformers of this type for 6.6-amp. alternating-current series lighting circuits. As with the indoor outfits, these transformers with minor changes in design can be arranged for operation on supply circuits of any commercial considerable expense were it not for the so-called safety coil or series transformer.

These low-voltage series circuits are usually supplementary to the regular or main street lighting system, and therefore, filling the same function, it is desirable to control them simultaneously with the main circuit.

Series transformers are designed to operate with the primary winding connected in series

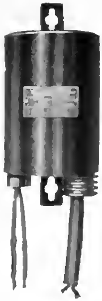


Fig. 12. Series Transformer for Aerial Mounting

Fig. 13. Series Transformer for Installation in Base of Post or in Manhole

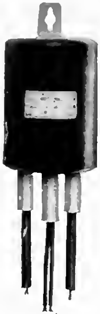


Fig. 14. Series Transformer for Subway Installation

with the main series circuit and the low-voltage secondary connected direct to the load, which insures simultaneous operation of the lamps in the main and supplementary circuits.

On the larger capacity transformers, protective devices are used to short circuit the secondary automatically when the auxiliary circuit opens so that the rise in voltage is limited at all times.

Some of the places where these transformers can be used to advantage are:

(1) In isolated side streets or alleys where it is desired to install a few series lamps.

(2) On poles, elevated structures, etc., where it is expedient to place a series circuit but where high potential would be objectionable.

(3) On bridges, and in underground circuits leading to ornamental posts.

(4) In installations for fire alarm boxes, police boxes, or letter boxes.

(5) For lighting aisles of safety.

(6) For house lighting near series circuits where high potential is not available.

The high efficiency of the high-current Mazda series lamps has made them very popular for street illumination. Individual auto-transformers have been commonly employed to operate them from standard constant-current series circuits. Recently, however, due to a number of inherent advantages, there has been a considerable demand for a small series transformer to operate a single lamp by stepping up the series line current to the higher current required by the lamp. These small transformers are also very extensively used to insulate a lamp of any current rating from the main circuit, and they are a valuable adjunct to "Safety First" in ornamental street lighting because they insulate the pole and lamp from the high-tension circuit and permit the use of high-efficiency series lamps in business districts where ordi-

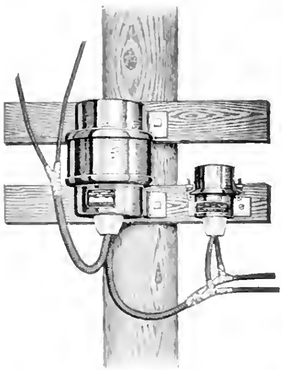


Fig. 15. Series Transformer (Large Capacity) and Protective Device

Fig. 16. Novalux Fixture Showing Auto-transformer or Compensator (Interior View)

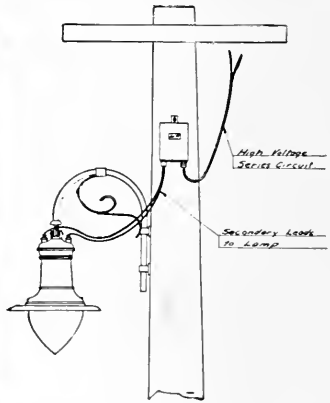


Fig. 17. Installation of Aerial Type Series Transformer

nances prohibit high-tension wires above the street surface.

The design of these transformers is such that with a lamp wattage variation of between 8 per cent above and 20 per cent below normal, the current on the secondary of the transformer will not vary more than 1 per cent with normal primary current and frequency, and a regulation characteristic is provided which protects the lamps at all times from surges on the lines.

When we consider that a 5 per cent increase in current decreases the life of a modern Mazda lamp to almost one third its normal value, we realize the importance of maintaining normal current on the lamp, and although the initial cost of an installation involving series transformers for every lamp must necessarily be somewhat high as compared with a straight series lamp installation, the saving in cost of high-voltage conductor heavy insulation, and high-tension cutouts, very materially assists in liquidating the difference in first cost.

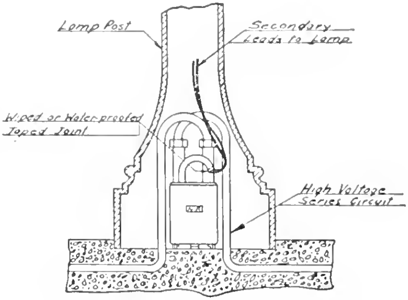


Fig. 19. Series Transformer Installed in Base of Post

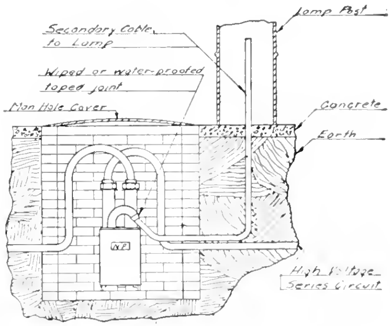


Fig. 20. Series Transformer Installed in Manhole

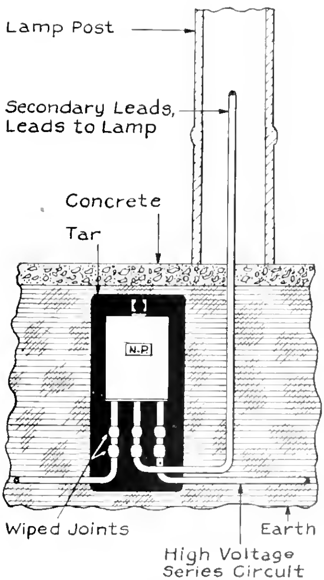


Fig. 18. Series Transformer Buried in Earth

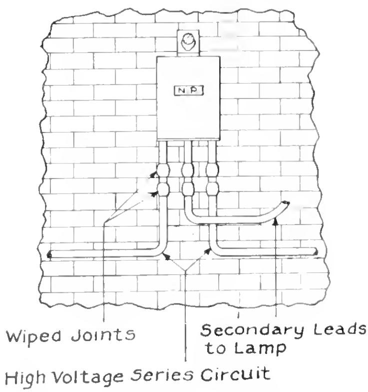


Fig. 21. Subway Installation in Series Transformer

The Magazine Film Cutout

THE SAFETY VALVE OF THE A-C. SERIES STREET-LIGHTING SYSTEM

H. E. Butler

Illuminating Engineering Laboratory, General Electric Company

A film cutout is necessary for each lamp on an alternating-current series lighting circuit in order that when any lamp fails the outage be not extended to the other lamps on the circuit. In this article, the old types of film cutout are compared with the new or magazine type, and recommendations are submitted as to the proper film cutout necessary to meet the requirements of different circuits. This invention of the author should be of particular value in the street lighting field and should be a means of indirectly promoting good street lighting throughout the country. No change in the design of the standard series socket and receptacle, used on series lighting circuits, is required in order to accommodate the magazine film cutout. This feature eliminates further investment and permits the lighting companies with their present system of street lighting to use this modern equipment and gain its many advantages.—Editor.

The film cutout used for alternating-current series street lighting systems on which Mazda lamps operate is known as the safety valve of the circuit. The device provides protection against a series circuit remaining open when a lamp fails.

The capacity of the circuit should be taken into consideration before installing film cutouts as there are two types of such cutouts recommended for alternating-current series circuits: the lead-disk film cutout which is tested for 70 volts and has probable limits of breakdown of 70 to 250 volts; and the magazine film cutout which is tested for 110 volts and has probable limits of breakdown of 250 to 400 volts. The former is recommended for circuits up to 3-kw. capacity and the latter is recommended for circuits exceeding 3 kw.

Table 1 gives the standard sizes of pole-type and station-type constant-current transformers that are available for street lighting together with their respective secondary voltages at half load, full load, and open secondary, and the film cutouts best suited for the different transformer capacities.

For some time there has been in use the aluminum disc film cutout which was tested for 110 volts and had probable limits for breakdown of 250 to 450 volts. This type of film cutout, which has been superseded by the magazine film cutout, consists of thin gauze placed between two aluminum discs held together by shellac. This construction required careful inspection in manufacture in order to assure uniform breakdown limits and to eliminate possible difficulty or trouble in actual operation such as having the film cutout puncture before lamps burned out, or having the discs separate in the lineman's pocket due to dampness and friction as shown in Fig. 1. Substitutes, such as heavy paper or electric tape, were sometimes used but these required a very high potential to puncture in order to close the circuit. The use of such makeshift materials might readily cause open circuits in the line and be responsible for placing in darkness the streets fed by that particular circuit. Yet, it was very difficult to manufacture a disk film cutout and be assured that these troubles could be entirely eliminated in actual service.

TABLE 1

POLE-TYPE CONSTANT-CURRENT TRANSFORMERS, 6.6-AMP. SECONDARY, 60 CYCLES

Capacity in Kw.	Secondary Voltages			Type of Film Cutout Recommended*
	Half Load	Full Load	Open Secondary	
1	76	152	226	Lead Disc
2	152	303	442	Lead Disc
3	228	455	660	Magazine
5	379	758	1095	Magazine
7½	568	1136	1635	Magazine
10	758	1515	2162	Magazine
15	1135	2270	3200	Magazine
20	1515	3030	4300	Magazine

STATION-TYPE CONSTANT-CURRENT TRANSFORMERS, 6.6-AMP. SECONDARY, 60 CYCLES

Capacity in Kw.	Secondary Voltages			Type of Film Cutout Recommended*
	Half Load	Full Load	Open Secondary	
5	379	758	819	Magazine
10	758	1515	1636	Magazine
15	1135	2270	2452	Magazine
20	1515	3030	3272	Magazine
25	1895	3790	4093	Magazine
30	2275	4550	4914	Magazine
40	3030	6060	6545	Magazine
50	3785	7570	8176	Magazine
60	4550	9100	9828	Magazine
70	5300	10600	11448	Magazine

*The types recommended have been based on the secondary voltage of the transformers, loaded, together with the maximum limit breakdown of the film cutouts plus 15 per cent.

Fig. 1

Fig. 2

Fig. 3

Fig. 3a

Fig. 4

Fig. 5

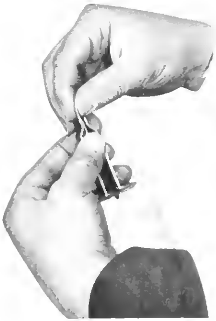


Fig. 6

Fig. 7

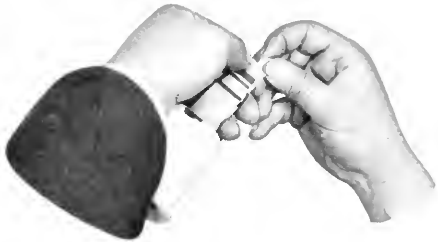


Fig. 8

Fig. 9

Fig 1. Old Aluminum-disc Film cutouts Which Have Separated
Fig 2. New Magazine Film Cutout
Figs. 3 and 3-a Comparison of the Old and New Cutouts, Based on an Equal Number of Renewals
Fig 4 Magazine Film Cutout Being Inserted in the Clips
Fig. 5. The Standard Series Socket Without Change Receives the Magazine Film Cutout
Fig. 6. Spreading the Socket Clips to Renew the Film
Fig. 7. Drawing Out and Centering the Film in the Socket Clips
Fig. 8. Tearing off the Used Section of Film After Renewal
Fig. 9. Discarded Punctured Section of Film

In order to eliminate these disadvantages, the magazine film cutout was developed. This device, as shown in Fig. 2, consists of a roll of special treated linen rolled inside of an insulated container having a slit to permit the film to be pulled out for renewal. The container protects the dielectric surface of the roll of film at all times and when installed is good for approximately 15 to 20 renewals which represents approximately 5 to 6 years of service.

As shown in Figs. 3a and 5, the magazine film cutout can be installed in the standard series socket universally used for series street lighting without any change whatsoever in the socket. In order to insure satisfactory operation of the magazine film cutout, the following instructions should be carried out:

(1) Pull the film out 3/4 inch from the capsule before inserting in the clips (see Fig. 4).

(2) Separate the socket clips to install the film roll, (see Fig. 4), and leave not more than 1/4 inch extended for finger hold (see Fig. 3a).

(3) To renew the film after puncturing, grip the capsule firmly and press down, thereby opening the socket clip (see Fig. 6). Make sure that the slit in the capsule faces the opening of the clip, then pull the film through leaving it centrally located in the clip (see Fig. 7.)

(4) After renewing the film, tear off the end section (see Fig. 8), allowing not more than 1/4 in. to project from the edge of the socket clip (see Fig. 3a) and discarding the punctured section (see Fig. 9).

Figs. 3 and 3a illustrate graphically the relative bulk or volume of the old single type film cutouts as compared with the magazine film cutout based on equal number of renewals.

The following gives some of the advantages gained by the use of this new magazine film cutout which is believed will eliminate many of the troubles that have been experienced with other types of film cutouts.

(1) The magazine film can be used with standard series sockets for street lighting without making any change whatever in the socket.

(2) Approximately 15 to 20 new dielectric surfaces are available with each roll of film, representing approximately 5 to 6 years of service.

(3) The film has a uniform dielectric strength.

(4) It eliminates the substitution of other materials which have been used invariably when the lineman did not have the standard film.

(5) Unlike other cutouts, the lineman may place it in his pocket without causing any danger to the dielectric surface of the film due to moisture and dirt as the film roll is enclosed in a highly insulated container.

(6) When renewing, the punctured portion of the film can be torn off without the use of an auxiliary cutter.

(7) When handling the film for renewing, the portion of the film which the finger touches is thrown away while with other types of repeating films the portion that is handled by dirty fingers is used for renewing the dielectric surface.

(8) With the magazine repeating film cutout, it is easier to get access to the film for renewing at night (which is generally the time when renewal takes place) than with other types of repeating films. Also, with other types, it is difficult to be assured that the film is properly renewed even on close inspection.

Good Street Lighting a Municipal Necessity

By Earl A. Anderson

Illuminating Engineering Section

Engineering Department, National Lamp Works of General Electric Company

The extensions in business occupations, industries, and social engagements after nightfall, made possible by developments in modern artificial interior lighting, have been so rapid that most municipalities have failed to keep pace in providing adequate illumination to permit safe and convenient usage of the streets. As a result, statistics show an alarming increase in accidents and crime. The remedy, its necessity, and effectiveness are very thoroughly and comprehensively treated in this article. Editor.

A single 2500-candlepower incandescent street lamp furnishes as much light as would a regiment of torch bearers with smoking fagots, the only street light available for venturesome parties who found it necessary to traverse city streets at night in the sixteenth century. However the dim flaring light from these hand-borne torches, though it was inadequate, was nevertheless undoubtedly more nearly equal to the requirements of that time than are many of the existing street lighting systems, considering the development of social, industrial, and commercial life of the present day. No longer are streets used at night only by the occasional wayfarer or an infrequent group happening forth because of some unusual occurrence; instead, a typical night street scene of today contains crowds of pedestrians, numerous street cars, and constant streams of motor vehicles of weight and speed beyond the imagination of those who lived in the days of torch bearers or link-boys.

How great a factor light is in making possible the extension of the natural day is perhaps most fully realized by those who had occasion to pass a night in London or one of the continental cities during the time of the late war, when all exposed artificial lighting including the street lighting was shrouded at night as a matter of protection against airplane raids. Many writers have attempted to express the peculiarly depressing consequence of the gloom, the loss of the sense of security and of personal safety. But perhaps more expressive are the statistics which showed an alarming increase in accidents and crime in these darkened cities, even though the unpleasantness of travel in dark streets had greatly reduced the amount of street traffic.

The truth is that the developments in modern artificial lighting in interiors have been such that business occupations, industries, sports, and social engagements in cities are carried on in the evening with the same degree of profit and pleasure as by daylight. This development has been so rapid, however, that in only a comparatively few cities is the degree of artificial street lighting adequate to accomplish fully its purpose of facilitating safe, comfortable, and convenient usage of the streets.

Proper Street Lighting Lessens Accidents

Much has been said as to the great saving in industrial costs from the reduction in plant investment made possible by a double-shift use of equipment. At the recent National

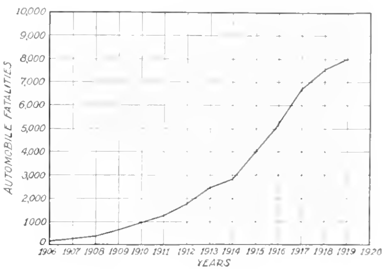


Fig. 1. Curve of Mortality from Automobile Accidents in United States, 1906 to 1919

Electric Light Association Convention in Chicago, Arthur Williams in speaking of electric vehicles called attention to the great economy in trucking costs by applying the double-shift idea to this work. He estimated possible cost reductions as great as one-half due to the increased utilization of equipment and terminal facilities and due to the use of the streets during the less congested hours. This night use of streets can be fully developed only by providing improved street lighting. The importance of the double-shift utilization of crowded thoroughfares should not be underestimated, for it must be remembered that also it effects a very important community economy by postponing the time when expensive duplicate thoroughfare construction will be required by the increasing volume of city street traffic. Possibly the full seriousness of the problem of handling the high-speed traffic, resulting from the almost universal adoption of automobiles as means of transportation, is not yet fully apparent. In 1910, 187,000 passenger and truck automobiles were produced; in 1920, 2,205,000. Today nearly 10,000,000 are traversing the highways and streets of the United States. Yet while in most cities street lighting has been improved to some extent, only in a small percentage has there been a radical improvement in proportion to the increased requirements.

The curve of Fig. 1 shows the rapid increase in fatal accidents due to motor vehicles in the United States during the period since 1906. It will be noted that while in 1906 the death total was only 183, in 1919 the total was 7,969. The curve is plotted from data compiled by The Prudential Insurance Company of America; and while reference is made to fatal accidents only, it follows that cases of lesser injury and property damage have been increasing at practically the same rate. This mounting total of personal and property damage has spurred both civic authorities and local and national safety associations to institute campaigns of education to induce greater care on the part of those using the streets both by day and night. However, in conjunction with the efforts to secure proper traffic regulation and the elimination of carelessness, it is necessary that there be an adequate and proper illumination of the streets, for at night on a poorly lighted thoroughfare even the best of care cannot reduce the accident risk to that of daytime.

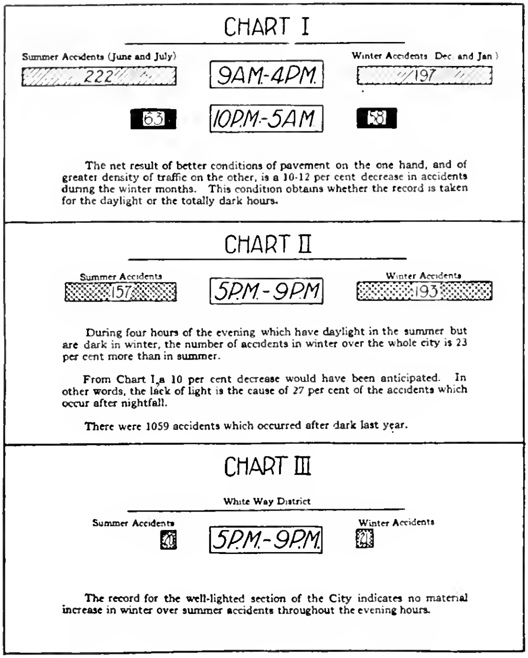


Fig. 2. Analysis of 3549 Accidents in Cleveland, Ohio, 1919, Showing the Relation between Street Lighting and Traffic Accidents

An estimate of the economic loss to the community resulting from automobile accidents was recently made by Dr. R. S. Vitt, Coroner of the City of St. Louis, and W. L. Patterson, a consulting engineer who has been investigating the number, types, and causes of automobile accidents in that city, month by month. Assuming an average length of life of forty-five years and an average yearly wage of $2000, Coroner Vitt estimates that the earning capacity of the 599 persons killed by automobile accidents in St. Louis during the last thirteen years could have exceeded $12,000,000. Mr. Patterson reports that during the year ending April 1, 1920, exactly $457,712.50 in property damages resulted from 8,537 street accidents of which 6,320 involved automobiles. Coroner Vitt's report also emphasizes the community loss beyond that of money value:

"Twelve million dollars," it states, "is an extremely low estimate of the amount of money 599 persons might earn in the course of their individual service to society during a life of even average length. This figure does not begin to represent the loss in dollars and cents to the community, and it does not take into account that greater loss which cannot be measured in money."

Nearly everyone is familiar with the accident data prepared by the Travelers Insurance Company showing that nearly twenty-four per cent of the industrial accidents have been attributed to lack of illumination. A survey of street accidents conducted in the City of Cleveland two years ago by Ward Harrison, Illuminating Engineer of the National Lamp Works, has shown that there is a similar definite relation between street lighting and traffic accidents. The chart of Fig. 2 summarizes the result of this survey of 3549 accidents during one year, 1059 of which occurred during the hours of darkness. Without taking space to go into the details of the survey, the essential point may be noted that the results showed that the lack of proper illumination contributed to fully twenty-seven per cent of the 1059 accidents which occurred after dark during that year in Cleveland. The survey further showed that while of course it is not possible at the present time to provide artificial street lighting which is fully as effective as daylight itself, nevertheless in the white-way district in Cleveland (lighted by 1500-candlepower lamps) the accidents did not increase with the failure of daylight at anything like the same rate as in the poorly lighted sections.

Following the completion of the Cleveland survey, similar investigations have been made in more than 30 other cities in the United States the results of which are not yet published but which show substantially the same indication of the importance of light in the reduction of traffic accidents. This evidence points to the serious responsibility upon those who have city management in charge, to take advantage of the permanent reduction in accident damage and loss of life afforded by properly planned and efficiently operated street lighting.

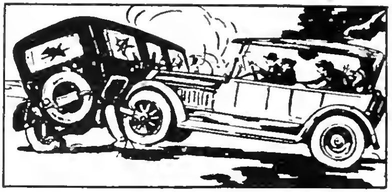



Fig. 3. Examples from a Series of Cartoons Embodied in Publicity Matter Recently Issued in the Interest of Better Street Lighting in Chicago

Good Street Lighting Lessens Crime

There is an inherent association between crime and darkness recognized by all. Throughout the ages the worst and vilest deeds have been done under cover of darkness. In fact, so well understood is the preference of the evil doer for darkness that headlines announce the unusual daring of the robber who commits a "daylight" crime while the same crime committed at night is noted in a paragraph as a commonplace. The recognized feeling of increased safety amid well lighted surroundings therefore rests upon a more substantial foundation than simply an inherited dread of the danger of darkness; for the wrongdoer makes his approach without warning when there are dark shadowy spaces, and his "get-away" is made many times more sure when there are conveniently dark passageways and alleys in which detection is difficult.

The effectiveness of street lighting as a deterrent to crime is crystallized in the oft quoted statement attributed to a former Mayor of Chicago to the effect that "a street lamp is as good as a policeman." While of course policemen are needed even in the daytime, there can be no question but that good street lighting is a powerful adjunct and aid to the force of law and order. The most striking illustrations of the importance of lighting in preserving community safety come when by accident or otherwise all street lamps are out for a period of time. For example in Chicago during the war an attempt was made to reduce coal consumption by extinguishing the street lamps. The following newspaper headlines indicate the immediate result:

ELECTRICITY THE SILENT POLICEMAN

CHICAGO DARK; BANDITS BUSY

THIRTY-TWO HOLDUPS AND MANY OTHER CRIMES IN TWO-DAY PERIOD

MAYOR'S MOTOR STOLEN

STREET LIGHTING, TURNED OFF TO SAVE COAL, TURNED ON TO SAVE PEOPLE

Needless to say it was decided that the street lighting was necessary even in the face of a severe fuel shortage.

Good Street Lighting Contributes Greatly to Comfort and Convenience

While the fundamental or elementary service performed by street lighting is that of accident and crime prevention, it has an equally important part in contributing to the comfort and convenience of the community. A satisfactory street lighting system not only makes possible the traversing of sidewalks and streets, but effectively reveals minor inequalities in sidewalks and paving surfaces and makes walking both safe and pleasant. Even in less frequented locations, a printed or written address is readable without striking a match. Street signs are well enough lighted to be easily made out without the necessity of stopping to decipher them. House numbers are visible at a reasonable distance. Passing friends may be recognized on the streets in any part of the city.

Present costs do not permit an equally high degree of illumination for all streets, but at least in the more congested areas a satisfactory level of illumination makes it possible to read newspapers or other matter while waiting anywhere on the sidewalk. The goal of a street lighting plan, which is reasonably attainable without an undue expenditure, should be that the normal daylight activities on streets may proceed at night practically without delay or increased difficulty.

Commercial Advantages of Well Planned Lighting

The distinct gain in business efficiency from the extension of the hours of operation through the safe and comfortable use of streets, made possible by good street lighting, has been referred to. Experience in dozens of communities has shown that proper illumination is of advantage in setting up favorable conditions for prosperity and progress in several ways. Light exercises a definite attraction for all people and it is a familiar story how the illumination of a white-way street lighting system changes a street, which previously was practically deserted after sunset, into a scene of activity and life throughout the evening hours. In specific instances where only one of two commercial streets was equipped with new lighting, the well lighted street has gained in the ratio two to one and even three to one in evening traffic as compared with the poorly lighted street. The effect upon property values of such a concentration of business is obvious to any one familiar with the way trade follows the crowd. Without considering the business interests of the merchants, well lighted business streets represent a real advantage to that very considerable number of the population engaged in work throughout the day and who therefore must do their shopping during the evening hours.

Progressive real estate promoters have realized the importance of good street lighting in adding to the attractiveness and value of property, and in developing new allotments. Therefore a liberal number of ornamental lamp posts are very commonly installed with underground current supply in place of the meager allowance of lighting equipment which is all the limited municipal appropriations will usually permit in outlying districts. This practice has not only been found to increase the sale value of the property but has sometimes been found to have the additional advantage that it enabled showing the property at night to prospective buyers some of whom were not able to arrange to come in the daytime.

Fig. 4. Euclid Avenue, Cleveland, Ohio, at Night. An Example of Modern Street Illumination

In the foregoing some of the possibilities of proper street lighting have been briefly outlined. Granting that these services are of obvious importance to a community, it is unfortunately true that in many instances there has been a tendency on the part of city administrators to hesitate in allowing any increase in appropriation for street lighting. Even in the face of conditions where two or even five times the existing illumination is really necessary, pressure for economy has sometimes induced consideration of plans for reduction of street lighting service. This is in contrast with the well recognized policy on the part of progressive cities to have municipal service of first quality in every department. Public structures generally represent the best in architecture for the purpose, and necessary appropriations are not begrudged to insure a proper street paving, the most efficient fire fighting equipment, and an effective police force. As a matter of fact dissatisfaction with rough broken pavements is soon evidenced by an insistent public demand for an expenditure to provide repairs and new paving. An inadequacy of fire fighting equipment which allows a fire to get beyond control is duly aired in the newspapers and in conversation so that the inefficiencies are soon remedied by new purchases. A series of bold robberies quickly develops public sentiment in favor of increased police protection.

An accelerated progress in providing street illumination sufficient in quantity, and an equal progress in adopting equipment which in appearance is in step with the efforts of private citizens and civic authorities to develop a city of good appearance, would therefore appear to wait only on a more widespread appreciation of what good street lighting means in preventing accidents, decreasing crime and in adding to the comfort, convenience, and personal profit of all.

The automobile, which is such an important factor in making necessary improved lighting, is in itself an agent for disseminating the necessity for good street lighting. It may be anticipated that inter-city touring which has become so popular will insure that representative citizens of poorly lighted communities will observe in actual demonstration the benefits of good street lighting in the few cities where desirable levels of illumination have already been approached.

That public appreciation of some of the functions of street lighting is increasing, is illustrated by a recent incident in a suburb of San Francisco. A woman was accidently killed by an automobile at a dark corner and in exonerating the driver of the machine the newspaper report states that the coroner's jury charged the Lighting Committee of the Board of Supervisors with the legal responsibility for the woman's death, basing their charge upon the circumstance that the location where the accident occurred was well known as a poorly lighted spot and that other juries had previously recommended that the Lighting Committee improve the illumination so as to eliminate the accident hazard.

Highway and Thoroughfare Lighting

By W. L. Harraden

Supply Department, General Electric Company

With the large and constantly increasing night traffic on our highways, the necessity for some form of illumination to cover at least the congested sections and danger points becomes more and more apparent. Automobile clubs and individuals in various parts of the country are pressing the matter with numerous town and county officials and it is probable that many more lighting installations of this nature will be made in the near future. The new Novalux highway lighting unit described in the following article provides a feasible and inexpensive solution of the problem.—Editor.

The latest addition to the street lighting family is a fixture to be known as the Novalux Highway Lighting Unit.

It consists of small reflectors scientifically shaped and so assembled that they do the work of an ordinary reflector 15 ft. in diameter. The engineers, in designing this unit, have evolved several new features because this unit is to be recommended for places that require a different distribution of light than has been previously considered. For instance, there is no need of lighting the vacant fields along the highways and therefore these reflectors have been so arranged that the bulk of light rays is collected and thrown up and down the road, very little going to the sides or in an upward direction.

The value of this construction can best be appreciated by referring to the photometric curve in Fig. 4, which shows that 3700 c.p. is obtained from each end of the fixture when only a 250-c.p. lamp consuming 155 watts is used. The light that falls upon the inside reflector is that which would ordinarily go beyond the outer edge of the outside reflector, therefore most of the upward and side light is greatly reduced and the downward light is increased that amount.

With this wonderfully efficient unit, highways can be illuminated at very little expense because there is little energy used and the cost of renewing the lamps is small. Furthermore, the long narrow beam of light from each end of this unit illuminates the road for a great distance in both directions, which fact makes unnecessary the placing of the units near together and thus minimizes the installation cost.

Excellent illumination can be obtained by spacing these units about 300 ft. apart and using 250-c.p. lamps, and very fine results can be obtained with spacings up to 600 ft. Larger lamps can be used if more light is desired.

If highways are properly lighted the glare from automobile headlights is less noticeable. In fact it will be possible to drive with the headlights dimmed.

As automobile owners appear to be acquiring the habit of spending a considerable portion of their evenings in driving for recreation, the lighting of the highways should be as seriously considered as that of city streets.

Fig. 1. Highway Lighting Unit, Showing the Nest of Parabolic Refractors on the Near Side and the Flexible Method of Mounting the Unit

Also, auto-express companies have sprung up all over the country and as a large percentage of the trucking is done over night, the lighting of highways is required for the convenience and protection of these trucks as well.

The six reflectors in this fixture are of fire enameled steel, three on each side. One lamp furnishes the illumination for both sides of the unit.

The fixture has an adjustable bracket so that the opening at the lower part of the reflector can be pointed direct to the road surface whether the pole is close to the edge of the road or sets back several feet. This adjustment also allows for tipping the reflector when installed on hills and at curves.

The units should be mounted from 30 to 35 ft. above the road surface. At first thought some people get the idea that there will be

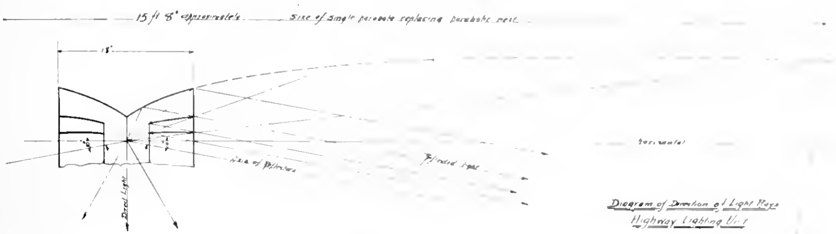


Fig. 2. Diagram Showing the Direction of Light Rays Emitted from the Highway Lighting Unit

Fig. 3. Paradise Road, Swampscott, Illuminated by Highway Lighting Units Containing 250-c.p., 4-amp. Mazda Lamps

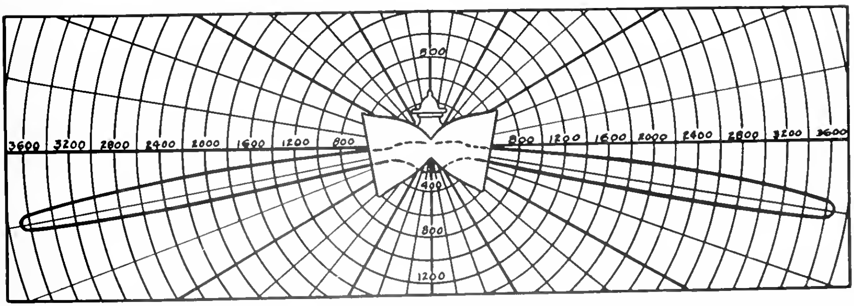


Fig. 4. Preliminary Photometric Distribution Curve of Light from a 250-c.p., 4-amp. Highway Lighting Unit Operated at 2500 Lumens

an enormous amount of glare, but this is not the case as the illuminating surface of the reflectors offsets the brightness of the lamp and one sees the unit as he would a large diffusing globe.

(c) By illuminating signs, sides of road, and obstacles.

2. Adds to comfort of night driving
   (a) By relieving eye strain
   (b) By assisting in making repairs

Fig. 5. Novalux Pendent Thoroughfare Lighting Unit with Reflector and Prismatic Dome Refractor

Fig. 6. Thoroughfare d-c. Series Luminous Arc Lamp with Prismatic Dome Refractor

Fig. 7 Novalux Pendent Thoroughfare Unit with Clear Rippled Globe and Prismatic Dome Refractor

Fig. 8. A Street Intermediate Between a Business District and Highway Lighted by Novalux Mazda Lamp Units Equipped with Refractors

Some of the advantages of highway lighting may be listed as follows:

1. Prevents accidents
   (a) By showing up dangerous curves
   (b) By reducing headlight glare
   (c) By discouraging hold-ups.
3. Increases night traffic and thereby relieves day congestion.
4. Decreases running time and increases road capacity.

5. Helps bring electricity to the farm by providing a pole line.
6. Increases real estate values
   (a) By tending to expand the city along the highways
   (b) By extending electrical conveniences.

Millions of dollars are appropriated every year for good roads. Soon we expect an additional allotment will be included for lighting the most congested highways. This money will be well spent if it accomplishes only one of the foregoing claims; the prevention of accidents.

Thoroughfare Lighting

Now as for lighting the thoroughfares connecting the highways with the business section of cities both the pendent 4, 5, and 6.6-amp. luminous arc and the 250, 400, 600, and 1000-c.p. incandescent fixtures are available. The incandescent units should usually be equipped with Holophane refractors. Where night traffic is very heavy on wide thoroughfares, large units should be spaced from 150 to 250 ft. on both sides of the roadway. As congestion decreases or the highway narrows, every other light may be omitted, preferably leaving a staggered arrangement. Mounting heights should be approximately 25 ft. and never less than 20 ft. Ordinarily long mast arms may be used but, where there are large thickly foliaged trees, best results are obtained from center span suspended fixtures.

In wholesale and manufacturing districts, where police and fire protection are of prime importance and where trees are scarce, a 600-c.p. lamp every 300 feet is sufficient.

Alternating-current Series Street Lighting Circuits

LINE LOSS ANALYSIS OF No. 6 AND No. 8 WIRE* AND PER CENT RELATION OF LINE LOSS TO LAMP WATTAGE

By H. E. Butler

Illuminating Engineering Laboratory, General Electric Company

This article analyzes the line loss of the cables that are commonly used for series street lighting circuits. The economical size of wire depends upon local conditions, such as: the size of lamp, the linear separation of lamps, whether an aerial or underground system, and the capacity of the circuit together with the prevailing cost of copper. In general, series street lighting circuits when once installed are permanent and are not replaced by new cable when obsolete illuminants are replaced by modern illuminants. This is evident when we consider that the majority of street lighting circuits installed when Elihu Thomson perfected his open carbon-arc lamp are still in use today for modern Novalux units equipped with Mazda series lamps. The author discusses the factors that should be taken into consideration before deciding upon the size of conductors and further shows the advantages which result from the use of large instead of small Mazda lamps on series circuits. —Editor.

Some of the factors which determine the margin of profit in operating an alternating-current series street lighting system are the size of wire used and the relation of line loss to lamp wattage.

The problem of selecting the conductor size for this type of circuit is exceptional in that the current density can be neglected. This condition results from the fact that the mechanical stresses, caused by suspension overhead or pulling into conduit underground, are so great that a wire large enough to be safe in these respects will be capable of carrying a current several times greater than the operating value. Of the variety of wire sizes available, No. 6 and No. 8 are now the most commonly used, the former being the ordinary size for aerial lines and the latter generally recommended for underground cables.

* Brown and Sharp gauge.

Following the introduction of the series system, constant-current transformers ranging in current rating from 1.75 to 10 amp. secondary have been installed. This wide range, however, necessitated carrying in stock such a variety of lamps, transformers, and accessories as to limit the commercial efficiency of the series system and accordingly the ratings were reduced in number to 5.5, 6.6 and 7.5 amp. There are in use today more circuits of 7.5 amp. than of 5.5 amp., but the number of either of these is considerably exceeded by that of 6.6-amp. circuits and the tendency is toward the standardization of this rating.

Explanation of the Charts

Fig. 1 presents data showing the relative line losses of 5.5, 6.6, and 7.5-amp. series circuits of various lengths for both No. 6 and

No. 8 conductors. These curves permit the ready determination of the advantage of one size of conductor over the other, but the prevailing cost of copper must be taken into consideration, that is, whether the interest and depreciation on the additional invest-

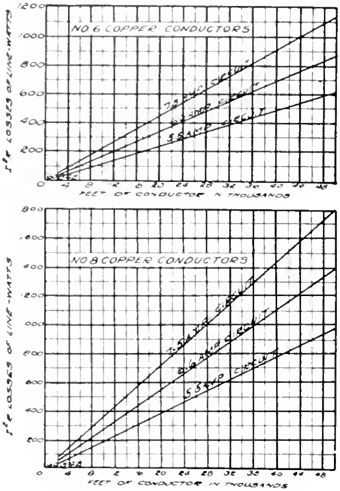


Fig. 1 Line Loss of No. 6 and No. 8 Conductor for 5.5, 6.6, and 7.5-amp. Circuits of Various Lengths

ment in No. 6 copper will be greater than the cost of power consumed in the extra line loss of No. 8 cable. This point is especially important in underground work as both No. 6 and No. 8 cables are used.

Fig. 2 gives the approximate relative cost of No. 6 and No. 8 cable for both aerial and underground services. It shows that for aerial service the cost is the same for all voltage insulations as weatherproof material is the standard insulation for all voltages, while for underground circuits this cost increases with the normal working pressure because of the increasingly heavy insulation that is necessary.

Figs. 3, 4 and 5 show the per cent relation of line losses to lamp wattage of 5.5, 6.6, and 7.5-amp. series circuits respectively for No. 6 and No. 8 wire with all standard sizes of series lamps.

Fig. 6 shows the relative I^2R and inductance losses for different operating currents in the line for both No. 6 and No. 8 cable with lead grounded and steel grounded armor. It will be seen that the losses in the line due to inductance are practically the same for both No. 6 and No. 8 copper. The inductance losses for No. 6 copper are practically in proportion to its I^2R losses while the inductance losses of No. 8 copper are about $\frac{2}{3}$ of its I^2R losses. This is true when the current does not exceed 20 amp.

Fig. 7 outlines briefly the types of cable used for aerial and underground series street lighting circuits. The insulations described are standard for the systems of distribution. It will be noted that the same insulation is used for the aerial cable regardless of what the normal working pressure may be (as aerial service does not require heavily insulated cable), therefore for aerial work the insulation cost of the cable does not increase with the normal working pressure, as is the case with the armored cable used for underground work. In the latter case the insulation is tested for approximately three times the normal working voltage in order to eliminate the possibility of grounds and to meet street lighting requirements.

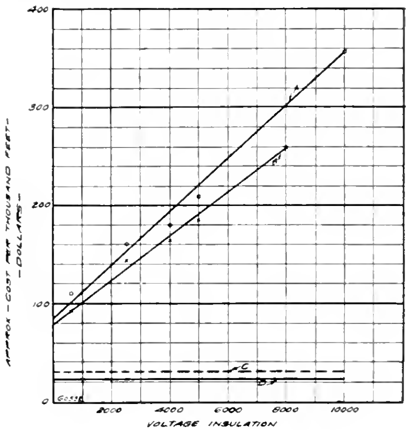
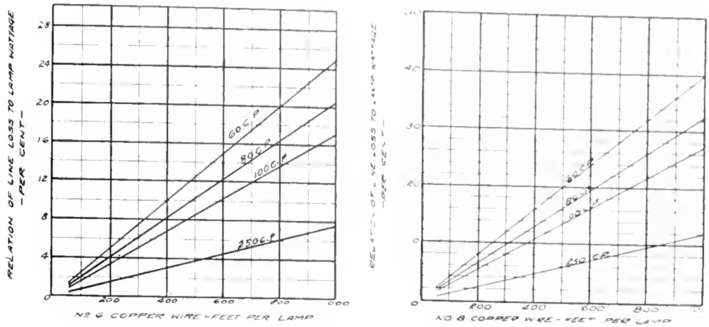


Fig. 2. Relative Cost of No. 6 and No. 8 Aerial and Underground Cable

A: No. 6 Underground Parkway Cable
B: No. 8 Underground Parkway Cable
C: No. 6 Aerial Cable, Same Insulation for All Voltages
D: No. 8 Aerial Cable, Same Insulation for All Voltages

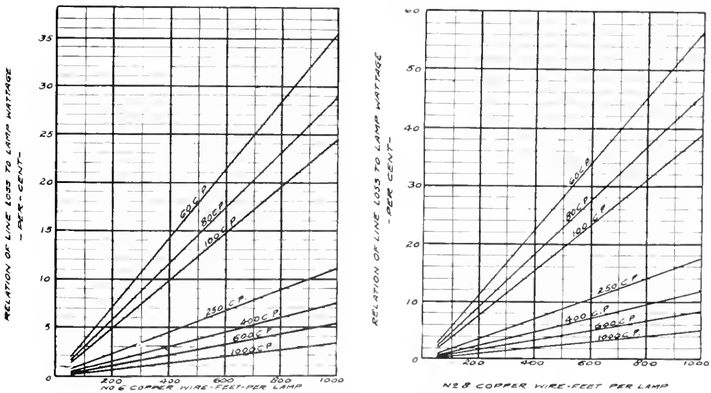
Figs. 3, 4 and 5 show the per cent relation of line losses to lamp wattage for 100 to 1,000 ft. of wire. This range represents the general length of copper wire that may be used per lamp in a total circuit. The tables



FEET PER LAMP = $\frac{\text{TOTAL FEET OF COPPER WIRE IN CIRCUIT}}{\text{NO OF LAMPS IN CIRCUIT}}$

LAMP	60 C P	80 C P	100 C P	250 C P
RATED WATTS PER LAMP	48.8	59.6	71.5	163
RATED LUMENS PER LAMP	600	800	1000	2500

Fig. 3. Relation of Line Loss to Lamp Wattage for 5.5-amp. Circuit of No. 6 and No. 8 Wire for All Standard Sizes of Series Lamps



FEET PER LAMP = $\frac{\text{TOTAL FEET OF COPPER WIRE IN CIRCUIT}}{\text{NO OF LAMPS IN CIRCUIT}}$

LAMP	60 C P	80 C P	100 C P	250 C P	400 C P	600 C P	1000 C P
RATED WATTS PER LAMP	49.2	60.6	71.4	159	* 234	* 330	* 544
RATED LUMENS PER LAMP	600	800	000	2500	4000	6000	10000

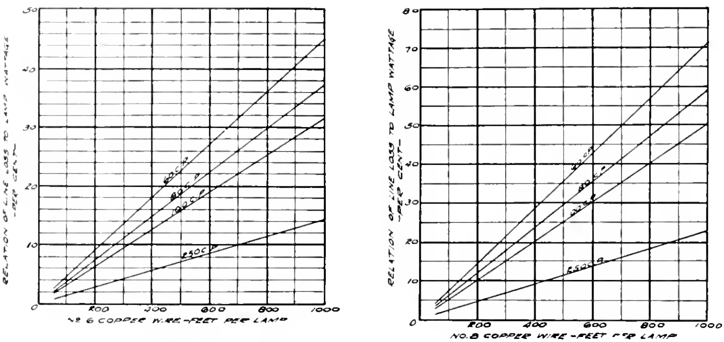
* WITH AUTO TRANSFORMER

Fig. 4. Relation of Line Loss to Lamp Wattage for 6.6-amp. Circuit for No. 6 and No. 8 Wire for All Standard Sizes of Series Lamps

below the curves show the standard range of series incandescent lamps for street lighting. The rated wattage and lumens per lamp are indicated for comparison and consideration.

To illustrate the usefulness of these curves consider the determination of the per cent relation of line loss to lamp wattage for the 6.6-amp. 60-c.p. lamp as compared with the 6.6 20-amp. 600-c.p. lamp* using 1000 ft. of No. 6 wire per lamp. By referring to Fig. 4, which gives these data for the 6.6-amp. circuit using No. 6 and No. 8 wire, it will be noted in the table that the wattage

The utility of Figs. 1, 2 and 6 may be illustrated by considering the advisability of using No. 6 and No. 8 wire for a 6.6-amp. underground system consisting of 40,000 feet of standard street lighting armored cable. Fig. 1 shows the relative line losses of 5.5, 6.6 and 7.5-amp. alternating-current series circuits of No. 6 and No. 8 copper wire and furnishes the data listed in Table I. It will be observed from these values that the I^2R line loss favors No. 6 cable by approximately a saving of $33.60 per year in power at 2 cents per kilowatt-hour for 4000 hr. per year.



FEET PER LAMP = TOTAL FEET OF COPPER WIRE IN CIRCUIT / NO OF LAMPS IN CIRCUIT

LAMP	60 C.P.	80 C.P.	100 C.P.	250 C.P.
RATED WATTS PER LAMP	50.4	61.1	71.4	159
RATED LUMENS PER LAMP	600	800	1000	2500

Fig. 5. Relation of Line Loss to Lamp Wattage for 7.5-amp. Circuit for No. 6 and No. 8 Wire for All Standard Sizes of Series Lamps

for the 60-c.p. lamp is 49.2 watts and the wattage for the 600-c.p. lamp with auto-transformer is 330 watts. The 60 and 600-c.p. curves for No. 6 wire in Fig. 4 show that the 6.6-amp. 60-c.p. lamp gives the relation of line losses to lamp wattage as 35.8 per cent and for the 600-c.p. lamp the percentage is 5.34. Therefore the wattage of the 60-c.p. lamp including line losses is $49.2 \times 1.358 = 66.8$, while the wattage of the 600-c.p. lamp including line losses is $330 \times 1.054 = 348$. Therefore, the operating efficiency of the 600-c.p. lamp is materially better than that of the smaller lamp and should encourage the use of larger lamps for street lighting.

* With auto-transformer.

TABLE I

6.6-AMP. CIRCUITS

Size Wire	I^2R Watts Lost in 40,000-ft. Circuit	Watts Difference I^2R Line Losses	Cost of Difference in Power at 2 Cents Per Kw-hr. for 4,000 Hr. Per Year
No. 6	690	420	$33.60
No. 8	1110		

From the curves in Fig. 6 can be determined the relation of I^2R loss and inductance loss for both No. 6 and No. 8 wire, lead grounded and steel grounded armor, for different operating currents based on 1000 ft.

of wire. The line loss due to inductance depends largely on local conditions such as the distance of separation between the wires, the overall thickness of the insulation, and whether the armor is grounded.

The line inductance loss varies considerably for different grades of steel armor. The bending and the variation of magnetic properties of the armor may also cause the loss to vary over a wide range. Therefore the inductance loss may differ greatly from the values indicated in Fig. 6. However, the curves represent practically average conditions that exist for the underground system of series street lighting. Therefore it will be found that while the I^2R line loss favors No. 6 armored cable, as is indicated in Table I, the loss due to inductance is practically the same for both No. 6 and No. 8 armored cable.

By referring to Fig. 2, the relative costs of No. 6 and No. 8 armored cable can be obtained. Consider that the load is 30 kw. non-inductive, the secondary current is 6.6 amp., and the normal working pressure or voltage is approximately $\frac{30,000}{6.6}$, i.e. 4550 volts. For the purpose, 5000-volt armored cable would be selected as this is the nearest standard available.

The cost, as derived from Fig. 2 for both No. 6 and No. 8 armored cable is given in Table II. These figures show that, on the basis of cost of cable, No. 8 is the more economical proposition as the interest and depreciation of the difference in the two investments for No. 6 and No. 8 copper represents a greater saving than the cost of power due to I^2R line losses as indicated in Table I.

There are other questions which might be solved by referring to Figs. 3, 4 and 5 such as determining the wattage difference of 5.5, 6.6 and 7.5-amp. circuits for any particular size of standard series lamp when using No. 6 and No. 8 copper. For instance, consider

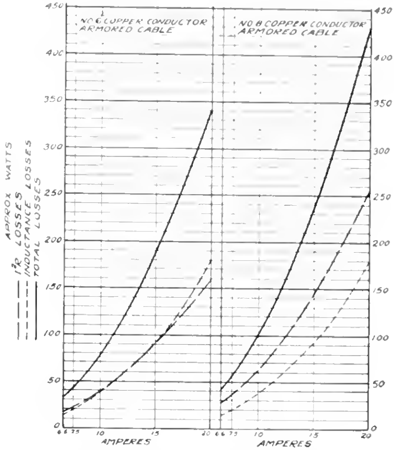


Fig. 6. Relation of I^2R and Inductance Losses in Line for No. 6 and No. 8 Copper Conductor Based on 1000 ft. Single-with conductor Cable 5/32 in. Overall Insulation Lead and Steel Grounded Armor

that it is decided to install a 6.6-amp. aerial series circuit using 100 lamps of 250-c.p. each and that it is desired to determine the relative wattage of this lamp including the line losses of either No. 6 or No. 8 copper with an

TABLE II

Size Wire	Cost for 1000 ft.	Cost for 40,000-ft. Circuit	Cost Difference	Difference in Interest Plus Depreciation at 12 Per Cent
No. 6	$221	$8,840	$1,240	$148.80
No. 8	190	7,600		

TABLE III

Size Wire	Lamp Wattage	Per Cent Relation of Line Loss to Lamp Wattage	Total Watts Per Lamp	Watts Difference for 100 Lamps	Difference in Cost of Power Computed for 4000 hr. at 2 Cents Per Kw-hr.
No. 6	159	4.5	166.2	360.	$28.80
No. 8	159	7.0	169.8		

average spacing of 400 ft. per lamp. From Fig 4, which gives these data for both No. 6 and No. 8 copper, is obtained the relation indicated in Table III.

In this case it will be observed that No. 6 copper is the more economical size of wire for

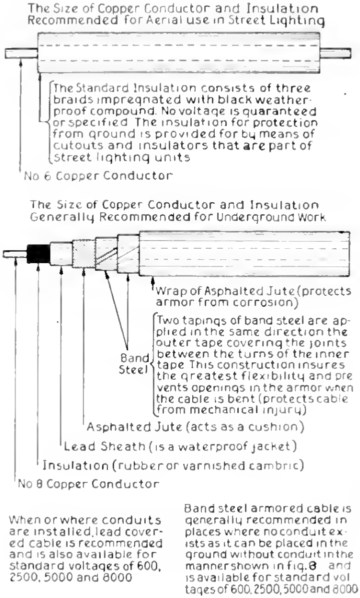


Fig. 7. Standard Insulations for No. 6 Aerial and No. 8 Underground Alternating-current Series Street Lighting Cables

aerial service. If however an underground system were under consideration, it would be found that the interest and depreciation on the difference in the two investments of No. 6 and No. 8 armored cable would favor No. 8 armored.

Inductance losses for cable that has only lead grounded armor with no steel armor is not as great as with cable that has steel grounded armor. This is due to the steel armor having highly magnetic properties.

In many large cities where conduit is used, the only armor employed is a lead cover as the conduit takes the place of steel armor. Therefore, with lead grounded armor and conditions similar to that outlined in Fig. 6, with the exception of armored steel tape, the loss due to inductance is practically 10 per cent of the I^2R losses. The inductance loss is therefore practically negligible as the I^2R loss of a constant-current series circuit is low compared to that of a multiple distribution circuit.

The practice of using lead covered and steel armored cable is popular because of the low initial cost and because conduit is not required since the steel armored cable meets the requirements fully.

Data on multiple systems have not been included in this article owing to the fact that series distribution is the more commonly used in this country today for street lighting.

Fig. 8. Band Steel Armored Cable is generally recommended in places where no conduit exists as it can easily be laid in the ground without conduit as shown in this illustration

There are of course isolated cases where the multiple system of distribution might be used to advantage, for example, where the multiple system is already available for street lighting and particularly when high-tension wires are prohibited. However, these cases are very few and the latter objection is hardly warranted due to the fact that today there are available constant-current transformers and auxiliaries which meet the low-voltage requirements. The reason why the series system of

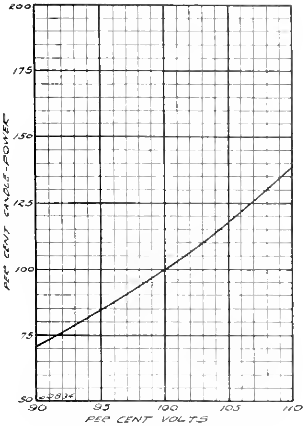


Fig. 9. Mazda Lamp Candlepower with Variation of Applied Voltage

distribution is more popular than the multiple system is due to the following advantages:

(1) It is impracticable if not impossible to select lamps for the individual voltage of each socket in a multiple circuit and consequently there results a variation in the life, efficiency, and candlepower all along the line. No two lamps will give the same life or the same amount of light. Fig. 9 shows the change in candlepower with respect to voltage drop.

On the other hand, every lamp in a series circuit is operated throughout its rated life at *rated current* and *efficiency*. The automatic regulating feature of the constant-current transformer maintains this condition. With this system there will be uniform life, uniform service, and uniform cost.

(2) The series circuit is the most economical method of wiring a street lighting system. There may be conditions where an equal number of lamps may be connected in multiple without using more copper but usually a multiple circuit will require approximately 50 per cent more linear feet of wire than a corresponding series circuit. Furthermore, if the capacity of the circuit exceeds 10 kw. the series circuit permits a further saving in the cost of copper because of the smaller diameter wires that are used.

(3) The series circuit permits instantaneous and simultaneous control from the central station.

(4) The rated life of series lamps is 35 per cent greater than that of multiple lamps.

(5) Based on approximately equal candlepower, the series filament occupies less space than the multiple lamp filament and this enables the former lamp to be placed more efficiently in focus with the refractor and thus a greater maximum candlepower can be obtained with it. (Note Fig. 10.)

It appears from the data shown on the various charts in this article that there is

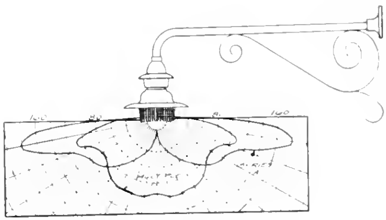


Fig. 10. Typical Difference in Characteristic Distribution of Light from Series and Multiple Street Lighting Mazda Lamps in the Same Unit

A: 71.4-watt (100-c.p.) Series Lamp with 6½-in. Holophane Prismatic Glass Band Refractor
B: 75-watt Multiple Lamp with 6½-in. Holophane Prismatic Glass Band Refractor

considerable advantage in the use of the larger lamps. This is particularly apparent from the curves of Figs. 3, 4 and 5 and a study of the per cent relation of the line loss to lamp wattage for the different series circuits covered.

List of Selected References on Street Lighting 1915-1921

By W. F. Jacob and A. A. Slobod

Main Library, General Electric Company

This list deals with electric street lighting only, primarily emphasizing the American practice. It is broadly classified according to the principal purpose of each article listed; thus, articles dealing chiefly with individual installations will be found under the sub-division "Description of Installations," while contributions giving cost data will be found under the sub-division "Cost." It is quite evident that many papers describing individual installations will also give some cost data, or articles under the sub-division "Street Lighting Units," may give some information on individual installations. The same is true of the other sub-divisions. A more detailed classification however would be impracticable. Under each sub-division the entries are arranged chronologically, the latest contributions appearing first. Earlier references of value, as well as information on books dealing with this subject, will be found in the bibliographies which are given under the sub-division "Reference Lists." Editor.

SYNOPSIS

GENERAL

1. National Electric Light Association.
   Report of Street and Highway Lighting Division.
   N. E. L. Proc. 43d convention, p. 258-63. 1920.

   Discusses lighting of parks, traffic accidents in relation to street lighting, fire department signals, lighting for traffic regulation, control for lighting and extinguishing lamps, the two-lamp unit feature, transformers, etc.

2. Rosse, C. A.
   Electrical system for a small town.
   Power Pl. Engng. v. 24, p. 1038. Nov. 1, 1920.

   Gives layout of a small central station and of a system of series incandescent street lamps.

3. Ryan, W. D'A.
   Intensive street lighting.
   G. E. Rev. v. 23, p. 362-73. May, 1920.

   The author reviews the new epoch in street lighting—the "intensive white way," which had its inauguration on the Pacific Coast and is rapidly spreading eastward. He points out the architectural, engineering, commercial and protective advantages of such a system and gives cost data on the various installations that have been made.

4. Underwood, W. E.
   Trend of modern practice in street lighting.
   Elec. Rev. Chgo. v. 76, p. 980-3. June 12, 1920.

   Discusses the influence of lighting on the welfare of municipalities, relation of traffic accidents to street illumination, practice in connection with transformers, mounting heights, glassware and series and multiple systems.

5. Wood, L. A. S.
   Tendencies in ornamental street lighting.
   Elec. Wld. v. 76, p. 324-25. Aug. 14, 1920.

   Discusses the parkway system and suggests proper method of installation.

6. Wood, L. A. S.
   Problems in ornamental street lighting.
   Elec. Rev. (Chgo.) v. 77, p. 241-2. Aug. 14, 1920.

   Discusses the general principles involved in installation of lighting systems, type of glassware and the avoidance of glare.

7. Present tendency in street lighting.
   Engng. & Contr. v. 54, p. 452. Nov. 3, 1920.

   Abstract of a report of the Committee on Street Lighting submitted at the annual convention of the American Society for Municipal Improvements.

8. Street lighting discussed by A.I.E.E. at Chicago.
   Elec. Rev. Chgo. v. 76, p. 117-8. Jan. 17, 1920.

   Review of the papers read by Messrs. Hurley and Harrison and of the discussion that followed.

9. Harrison, W.
   Street lighting and traffic accidents.
   Elec. Rev. (Chgo.) v. 75, p. 605-6. Oct. 11, 1919.
   Sci. Amer. S. v. 88, p. 307. Nov. 22, 1919.
   Illum. Engr. v. 12, p. 286. Oct., 1919. Condensed.

   Analysis of year's traffic accidents in Cleveland as to time of day and season shows large percentage due to lack of light. Value of good street lighting is shown.

10. National Electric Light Association.
    Report of Chairman of Committee on Commercial Aspects of Street and Highway Lighting.
    N. E. L. A. Proc. 42d convention, Commerical section, p. 171-81. 1919.

    Primarily a discussion of the report submitted in 1917.

11. Cravath, J. R.
Lighting of streets in residential sections.
Elec. Wld. v. 70, p. 565-8. Sept. 22, 1917.
General principles for observance in lamp spacing and location with overhead circuits under the conditions that are normally found to exist in small towns and cities.

12. Cravath, J. R.
Residential street-lighting equipment.
Elec. Wld. v. 70, p. 611-3. Sept. 29, 1917
Principles involved in selecting lamps and accessories, in determining lamp heights and in installing ornamental systems in small towns and cities.

13. Cravath, J. R.
Street lighting for business districts.
Elec. Wld. v. 70, p. 664-6. Oct. 6, 1917.
Principles involved in spacing and in selection of lamps and accessories for ornamental systems in small cities and towns, with a discussion of the relative merits of series and multiple distribution.

14. National Electric Light Association.
Report of Sub-Committee on Commercial Aspects of Street and Highway Lighting.
N. E. L. A. Proc. 40th convention, Commerical section, p. 327-38. 1917.

15. Bell, L.
Exterior illumination.
Elec. Rev. & W. Elec'n. v. 69, p. 676. Oct. 14, 1916.
Abstract of a lecture on street lighting given under the auspices of the Illuminating Engineering Society.

16. Doane, S. E.
Civic duty for the engineering profession.
Elec. Rev. & W. Elec'n. v. 69, p. 1135-7. Dec. 30, 1916.
Includes a discussion of street lighting development and the duties of the engineer to encourage further progress in this direction.

17. Kelly, T. F.
Selling municipal and highway lighting.
Elec. Rev. & W. Elec'n. v. 68, p. 915-7. May 20, 1916.
Opportunities for the central station in the development of highway and street lighting.

18. Lacombe, C. F.
Street lighting fixtures, contracts, etc.
Elec. Rev. & W. Elec'n. v. 69, p. 761. Oct. 28, 1916.
Abstract of a lecture given under the auspices of the Illuminating Engineering Society.

19. Millar, P. S.
Present day tendencies in street lighting.
Elec. Rev. & W. Elec'n. v. 69, p. 415-7. Sept. 2, 1916.
A discussion of the various types of illuminants and street-lighting accessories available; data on installation practice and operation and some of the engineering aspects of street lighting.

20. Association of Edison Illuminating Companies.
Report on the Committee on Street Lighting.
25 p. 1915.
Results of tests of visibility, uniform illumination, etc.

21. Stickney, G. H.
Street lighting practice with incandescent lamps.
Munic. Engng. v. 48, 80-8. Feb., 1915.
Part of a paper prepared for the American Society of Municipal Improvements. Lays down the principles which have been developed and gives details of some installations.

22. Lacombe, C. F.
High intensity street lighting of European cities compared with New York.
Illum. Engng. Soc. Trans. v. 9, p. 614-32. No. 7, 1914.
Factors and consideration which influence the design of street lighting installations are outlined; differences between European and American practice are pointed out. The paper is concluded with illustrations and descriptions of typical European installations.

PRINCIPLES OF STREET ILLUMINATION AND PHOTOMETRY

23. Rose, S. L. E. and Butler, H. E.
Single light compared with cluster units for street lighting.
G. E. Rev. v. 22, p. 1044-55. Dec., 1919.
Deals with two types of ornamental incandescent street lighting unit, the old five-light cluster unit of ball globes and the modern single-light Novalux unit. Points out the inefficiency of the cluster unit and presents data to show why this type of unit should be discarded.

24. Luckiesh, M.
Aesthetics of street lighting.
Illum. Engng. Soc. Trans. v. 13, p. 355-6. No. 6, 1918.
Abstract of a paper presented before the Society.

25. Rose, S. L. E. and Butler, H. E.
Ornamental utilitarian street lighting units.
G. E. Rev. v. 21, p. 430-5. June, 1918.
A companion to "Street lighting with modern electric illuminants," which appeared in the December, 1917, issue of the General Electric Review, v. 20, p. 945-63. Deals with some new types of units.

26. Cravath, J. R.
Street lighting for small cities and towns.
Elec. Wld. v. 70, p. 414-7. Sept. 1, 1917.
General principles are discussed, including brightness, silhouette effect, shadows, glint, glare, spacing and shade tree interference.

27. Peterson, E.
Utilization factors for street-lighting units.
Elec. Wld. v. 69, p. 1156-7. June 16, 1917.
Method of calculating flux incident upon street surfaces from the zonal candle-powers of the lighting units.

28. Rose, S. L. E. and Butler, H. E.
Street lighting with modern electric illuminants.
G. E. Rev. v. 20, p. 945-63. Dec., 1917.
This paper amounts practically to a handbook on street illumination, covering both incandescent and arc lamps from the illumination standpoint, and enables anyone having to do with street lighting to compare different units on the basis of illumination. It discusses the various factors entering into street lighting contracts which should be thoroughly understood by all parties concerned in order to avoid controversies later.

29. Millar, P. S.
Tests of street illumination.
Illum. Engng. Soc. Trans. v. 11, p. 479-508; discussion, p. 508-17. No. 4, 1916.
Author is concerned with special investigations of the effectiveness of street lighting, and describes methods which have been developed for such investigations.

30. Glare in street lighting.
Illum. Engng. Soc. Trans. v. 11, p. 518-24. No. 6, 1916.
Report of the Committee on Glare. The laws governing glare are outlined and the causes of glare in street lighting discussed.

31. Millar, P. S.
Effective illumination of streets, with discussion.
Illum. Engng. Soc. Trans. v. 10, p. 1039-58; discussion, p. 1058-79. No. 9, 1915.
Discusses more particularly those aspects of effectiveness which are dependent upon skilful utilization of the light to produce the most effective illumination.

DISTRIBUTION SYSTEMS

32. Harrison, W.
Multiple systems of distribution for street lighting.
A.I.E.E. Jour. v. 39, p. 7-12. Jan. 1920.
Elec. Rev. (Chgo.) v. 76, p. 102-5. Jan. 17, 1920. Condensed.
Elec'n. (Lond.) v. 85, p. 324-6. Sept. 17, 1920. Condensed.
Describes various devices in use or proposed for control of multiple street lamps and outlines characteristics desirable in such apparatus. Calls attention to the small differences in efficiency of present multiple and series incandescent lamps.

33. Hurley, W. P.
Series system of street lighting distribution.
A.I.E.E. Jour. v. 39, p. 1-6. Jan., 1920.
Elec. Rev. (Chgo.) v. 76, p. 100-2. Jan. 17, 1920. Condensed.
Elec'n. (Lond.) v. 85, p. 326-7. Sept. 17, 1920. Condensed.
Reviews the advantages of the series system and states that any system of street lighting of sufficient merit to supersede the series system must depend primarily on the development of simple, reliable and inexpensive apparatus for the individual lamps to enable them to be operated on the existing multiple distribution circuits.

34. Steinmetz, C. P.
Constant-potential series system for street lighting.
A.I.E.E. Jour. v. 39, p. 245-8. Mar., 1920.
Elec. Rev. (Chgo.) v. 76, p. 105-8. Jan. 17, 1920.
Sci. Am. Mo. v. 1, p. 566-7. June, 1920. Abstract.
Elec. Wld. v. 75, p. 678. Mar. 20, 1920. Abstract.
Comparison of three types of high-voltage street lighting systems: constant-current series, constant-potential series and constant-potential multiple.

35. Ferry, M. and Tompkins, E. M.
Economics of group system of street lighting.
Elec. Wld. v. 68, p. 177-8. July 22, 1916.
It is a development of the series multiple system and consists of a number of small series circuits, each served by a low potential transformer, the primaries of these group transformers being connected in series to a constant-voltage high-potential source of supply. It is used in Chicago, Ill.

36. Uptegraff, R. E.
Characteristics of a series lighting system.
Elec. Wld. v. 68, p. 79-80. July 8, 1916.
Variations in current and power-factor when lamps burn out and the regulation of a system using constant over-all voltage.

37. National Lamp Works—General Electric Co.
Street series alternating-current incandescent lamp circuits.
Engineering Department Bul. No. 25. 23 p. Sept. 20, 1915.
Factors in design and operation.

STREET LIGHTING UNITS

38. Butler, H. E.
Enclosed carbon arc lamps vs. Novalux Mazda units.
G. E. Rev. v. 23, p. 534-49. June, 1920.
Author proves that an appreciable waste of power exists in street lighting systems because of the use of the enclosed carbon arc lamp.

39. Cameron, A. D. and Halvorson, C. A. B.
Developments in street lighting units.
Illum. Engng. Soc. Trans. v. 15, p. 163-8; discussion, p. 168-74. No. 3, 1920.
Recent progress.

40. Kegley, H. C.
Topical lamp post.
Sci. Am. v. 122, p. 425, 439-40. Apr. 17, 1920.
Symbolic posts of California towns and cities. Each design in some way incorporates a feature of the town's history or present points of interest.

41. Wood, L. A. S.
Ornamental street lighting.
Elec. Jour. v. 17, p. 195-7. May, 1920.
Various designs of posts and lanterns are illustrated.

42. Magnusson, C. E.
Ornamental concrete lamp posts. 22 p. 1919.
Engineering Experiment Station. University of Washington Bulletin No. 6.

43. Willcox, F. W.
Gas-filled lamp and its effect on illuminating engineering.
Illum. Engr. v. 12, p. 148-51. June, 1919; discussion, v. 12, p. 161-71, 179-81. June-July, 1919.

44. Cravath, R.
Street-lighting poles and lamp supports.
Elec. Wld. v. 70, p. 514-16. Sept. 15, 1917.
Equipment adaptable to small cities and towns. Describes the poles and lamp supports available for the different conditions attending upon residential and business section lighting, and underground and overhead construction. Wood, iron, steel and concrete posts are considered.

45. Cravath, J. R.
Street lighting units in the smaller cities.
Elec. Wld. v. 70, p. 473-7. Sept. 8, 1917.
Particular attention is given to lamp rating and to the relative value of different accessories under certain conditions of spacing and type of street. The relation between first cost and operating cost of gas-filled incandescent lamps and magnetite arcs is emphasized.

46. Harrison, W.
Combination of refractor and diffusing globe for street lighting.
Illum. Engng. Soc. Trans. v. 12, p. 305-9; discussion, p. 309-18. No. 7, 1917.

47. Light-directing shades.
Elec. Wld. v. 70, p. 646. Sept. 29, 1917.
Made by the G.E. Co.

48. Mast arm for series street-lighting units.
Elec. Wld. v. 70, p. 352. Aug. 25, 1917.
Replaces center-span suspension as used for carbon arc lamps and eliminates the pole on opposite side of street.

49. Ornamental street-lighting with Union metal standards.
Elec. Rev. (Chgo.) v. 71, p. 381-2. Sept. 1, 1917.

50. Stippled globes and refractor for Novalux street lighting fixture.
Elec. Rev. (Chgo.) v. 71, p. 784. Nov. 3, 1917.
Illustrated description of the G. E. equipment

51. Street lighting units.
Elec. Wld. v. 69, p. 635. Mar. 31, 1917.
An artistic fixture which contains a prismatic reflector; it has been developed by the General Electric Co.

52. Halvorson, C. A. B. and others.
Arc lamps for street illumination.
Illum. Engng. Soc. Trans. v. 11, p. 251-68; discussion, p. 315-30. No. 3, 1916.
An appendix gives tabulated data on numerous street lighting installations and the operation characteristics of several forms of arc lamps.

53. Marple, A.
Originality in street lighting standards.
Munic. Engng. v. 51, p. 95-6. Sept., 1916.
Illustrates and describes the beautiful standards used in Southern California.

54. Designs of ornamental street-lighting posts.
Elec. Rev. & W. Elec'n. v. 68, p. 937. May 20, 1916.
Made by the King Foundry Company, St. Joseph, Mo.

55. Inexpensive lamp standards suitable for many occasions.
Elec. Wld. v. 67, p. 44. Jan. 1, 1916.
Method of construction of temporary posts.

56. Bell, L.
Modern street-lighting units.
Elec. Rev. & W. Elec'n., v. 66, p. 1038-9. June 5, 1915.
History of development and modern tendencies.

57. Novalux lighting
Munic. Jour. v. 40, p. 219-20. Feb. 10, 1916.
G.E. units.

58. Path-finder lamp post.
Munic. Jour. v. 41, p. 720-1. Dec. 7, 1916.
For lighting drive-ways in parks and similar service; made by Smyser-Royer Company of Philadelphia.

59. Pressed-steel ornamental lamp standards.
Elec. Rev. & W. Elec'n. v. 68, p. 348. Feb. 19, 1916.
Made by Union Metal Manufacturing Co. Canton, Ohio.

60. Street lighting standards.
Munic. Jour. v. 41, p. 620 Nov. 16, 1916.
Made by Union Metal Manufacturing Co., Canton, Ohio.

61. Butler, H. E.
Parallel vs. staggered arrangement of lamps.
Elec. Wld. v. 66, p. 1027-8. Nov. 6, 1915.
An investigation of the relative merits of the two systems of installing ornamental street lighting standards.

62. Hurl[illegible], W. P.
Street lighting [illegible]
Illum. Engng. [illegible] *Tran*[illegible] 10, p. 405-[illegible] No. 5, 1915
Review of [illegible]

63. Mahan, H. E., and Ba[illegible], H. E.
Ornamental street lighting systems compared.
Elec. Wld. v. 66, p. 180-2. July 24, 1915.
Relative advantages of the single unit and the cluster are analyzed from the architectural and the engineering viewpoint.

64. National Lamp Works—General Electric Co.
Street series Mazda lamps.
Engineering Department Bul. No. 11c. 10 p. Oct. 15, 1915.
Characteristic curves, etc.

65. Novalux units for Mazda series street lighting.
Elec. Rev. & W. Elec'n. v. 67, p. 910-1. Nov. 13, 1915.
Made by the G. E. Co.

66. Street lighting fixtures.
Munic. Engng. v. 48, p. 8-9. Jan., 1915.
Illustrates and describes new forms of fixtures suitable for the modern high candle-power incandescent lamp. Deals primarily with the Novalux units.

DESCRIPTION OF INSTALLATIONS

67. Hinson, N. B.
Conduit return underground series system.
Jour. Elec. v. 46, p. 67-8. Jan. 15, 1921.
Elec. Wld. v. 77, p. 206. Jan. 22, 1921. Condensed.
Describes the installation at Beverly Hills, Cal.

68. Halvorson, C. A. B. and Oday, A. B.
Street lighting with low mounted units; Kensico dam roadway, with discussion.
Illum. Engng. Soc. Trans. v. 15, p. 153-62. Apr. 30, 1920.
Gives specifications for the units used and discusses the application of these units to street lighting.

69. Ryan, W. D'A.
New intensive street lighting.
Jour. Elec. v. 44, p. 151-2. Feb. 15, 1920.
Describes the white way improvements in Los Angeles, Cal.

70. Saratoga's variable lighting system.
Pub. Wks. v. 48, p. 180. Mar. 6, 1920.
Elec. Rev. (Chgo.) v. 76, p. 432-3. Mar. 13, 1920.
Dual system which gives white way illumination during summer and modified illumination during the remainder of the year.

71. Street lighting improvements in London.
Elec'n. (Lond.) v. 85, p. 478. Oct. 22, 1920.
Illustrated description of the improvements effected in the lighting of part of the city of Westminster. Gas-filled incandescent lamps in conjunction with scientifically-designed fittings were used.

72. Street lighting with ornamental posts in Pasadena.
Elec. Rev. (Chgo.) v. 77, p. 916. Dec. 11, 1920.
Boulevard type units are employed, equipped with 80-candle-power, 6.6-amp. type C lamps. Installation costs ranged from $0.65 to $0.80 per front foot of property. Novalux units are placed in locations where a greater volume of illumination is required.

73. Cravath, J. R.
How wattage of luminous arcs was reduced in Detroit.
Elec. Wld. v. 74, p. 580. Sept. 13, 1919.
Method used to change magnetite-arc lamps for operation on 272 watts, instead of 310 watts, to get additional lamps on various circuits.

74. Dickerson, A. F.
Lighting San Francisco's triangle district.
Jour. Elec. v. 42, p. 414-15. May 1, 1919.
That the arc light still holds its own in the field of street lighting is testified by the success of this installation. The pleasing and adequate nature of the resulting illumination has already lead to its serving as a model for the street lighting of several other cities.

75. Gaster, L.
Street lighting reconstruction problems.
Illum. Engr. v. 12, p. 225-32; discussion p. 233-6. Aug., 1919.
Elec. Rev. (Chgo.) v. 75, p. 59. July 12, 1919. Abstract.
Examination of official data in city of London on street accidents which took place at the time street lighting was curtailed during the war.

76. Keith, W. G.
Development of the Chicago street-lighting system.
Engng. Wld. (Chgo.) v. 15, p. 39-44. Dec. 15, 1919.
Elec. Rev. (Chgo.) v. 75, p. 559-61. Oct. 4, 1919.
Installation and operation of series group systems. Paper read before the International Association of Municipal Electricians.

77. Kleine, Wm. O.
A modern ornamental street lighting circuit.
Am. City, City edition. v. 20, p. 535-7. June, 1919.
Cast iron standards about 13 ft., 4 in. high carrying 600-candlepower Mazda C lamps used in Cincinnati.

78. Murphy, F. H.
Park and boulevard lighting in Portland (Oregon)
Elec. Wld. v. 73, p. 889-90. May 3, 1919.
An artistic effect has been arrived at by the employment of concrete posts with Alba globes. Substations combined with comfort houses and tool shelters are a feature. Steel-armored, lead-covered underground cable was used for a 6.6-amp., constant-current series incandescent system.

79. Rowe, L.
Street lights in Columbus.
Munic. Jour. v. 46, p. 264. Apr. 12, 1919.

80. Schwartz, W. F.
The street lighting of the city of Buffalo.
Am. City. v. 48-50. Jan., 1919.
System comprises type C nitrogen-filled lamps, luminous arcs, pendent magnetite arcs and enclosed carbon arcs. Gives number and cost of each type.

81. Toensfeldt, R. T.
Street lighting problem of the city of St. Louis.
Munic. Engng. v. 57, p. 166-8. Oct., 1919.
Reviews the lighting contracts of St. Louis and makes suggestions for future developments.

82. Harrison, H. T.
Present and future electric street lighting in Islington.
Elec'n. (Lond.) v. 80, p. 690-1. Feb., 1918.
Illum. Engr. v. 11, p. 161. June, 1918. Condensed.
Discusses the proposed substitution of arc lamps by half-watt lamps.

83. Features of Chicago's new parkway lighting system.
Elec. Wld. v. 71, p. 516. Mar. 9, 1918.
Details of construction, including method of running circuits and use of series multiple transformers with special couplings.

84. The lighting of London: past, present and future.
Illum. Engr. v. 11, p. 225-6. Oct., 1918.
Editorial review

85. Allen, W. C.
Street lighting in the national capital.
Am. Inst. Arch. Jour. v. 5, p. 339-42. July, 1917.
Details of the installation.

86. Keith, W. G.
Group street lighting system for the city of Chicago.
G. E. Rev. v. 20, p. 126-9. Feb., 1917.
Gives details of the system that is novel for large installations and plans for the future.

87. Kingsbury, E. F.
Historical lighting of Independence Square, Philadelphia.
Illum. Engng. Soc. Trans. v. 12, p. 449-56; discussion, p. 456-63. No. 9, 1917.
The units are described in detail and several photographs of different units are shown. Considerable material of historical and educational interest is included, descriptive of early lighting in Philadelphia after which installations the equipments were copied.

88. Rice, R. H.
Modern street lighting an asset to Spokane.
Elec. Wld. v. 70, p. 418. Sept. 1, 1917.
G. E. magnetite arc lamps. Aspect of streets, appearance of crowds and morality, peace and order improved by new lighting system in business section.

89. Thompson, R. B.
Development of a permanent street lighting plan for a small city and village, with discussion.
Illum. Engng. Soc. Trans. v. 12, p. 260-9. No. 6, 1917.
Practice of the Central Hudson Gas and Electric Co., serving a territory of about 600 sq. miles, including the cities of Newburgh and Poughkeepsie.

90. Unusual street lighting practice for small towns.
Elec. Wld., v. 70 p. 1141. Dec. 15, 1917.
West Liberty, Iowa, with a population of 1700 spent $12,000 on street lighting with ornamental posts and underground service.

91. Dempsey, W. T.
Electric street lighting in New York City with particular reference to the borough of Manhattan.
Illum. Engng. Soc. Trans. v. 11, p. 1137-43. No. 9, 1916.
Elec. Jour. v. 14, p. 3-6. Jan., 1917. Condensed.
Reviews progress.

92. Mendenhall, B. W.
Ornamental lighting in Salt Lake City under the new lighting-improvement district law.
Elec. Wld. v. 67, p. 1313. June 3, 1916.

93. Ryan, W. D'A.
Downtown lighting system for San Francisco.
Elec. Wld. v. 68, p. 457-9. Sept. 2, 1916.
Combination of trolley poles and lighting standards of dignified artistic designs on Market Street. Floodlighting of building façades and use of toned glassware results in distinctive lighting.

94. Shaw, C. H.
Street lighting system of Sheboygan, Wis.
Elec. Wld. v. 68, p. 464-5. Sept. 2, 1916.

95. Tinson, H. A. and Diggs, D. M.
Model street lighting installation at Port Jervis, N. Y.
G. E. REV. v. 19, p. 225-9. Mar., 1916.
Munic. Engng. v. 51, p. 5-8. July, 1916.
Pertinent details of the cost, layout, construction, operation and appearance of the installation using Edison Mazda series lamps.

96. Cleveland's new street lighting installation.
Elec. Rev. & W. Elec'n. v. 68, p. 750-1. Apr. 29, 1916.
Nitrogen-filled lamps in specially designed antique lanterns used with marked success in business district. Initial cost is $228 per unit.

97. Most elaborate street lighting inaugurated in San Francisco.
Elec. Rev. & W. Elec'n. v. 69, p. 624. Oct. 7, 1916.
Market Street installation.

98. Salt Lake City's white way.
Elec. Wld. v. 68, p. 701. Oct 7, 1916.
New system designed by W. D' A. Ryan covers retail business district.

99. Salt Lake City's splendid new street lighting.
Elec. Rev. & W. Elec'n. v. 69, p. 626-7. Oct. 7, 1916.

100. Special lighting of downtown Chicago street by Merchants' Association.
Elec. Wld. v. 68, p. 771-2. Oct. 14, 1916.

101. Street lighting in Detroit.
Munic. Engng. v. 50, p. 128-30. Apr., 1916.
Brief history of the municipal plant and recent operations.

102. $3,750,000 for Chicago street lighting.
Elec. Wld. v. 67, p. 1436-7. June 17, 1916.
Incandescent lamps of 600 candle-power and 100 candle-power with substation and generating units provided to augment present equipment.

103. Conant, W. B.
Street Lighting in London.
Municipal Engng. v. 48, p. 333-6. June, 1915.

104. Harrison, W.
Cleveland lantern for ornamental lighting
Elec. Wld. v. 66, p. 521-4. Sept. 4, 1915.
Discusses selection of glassware for lanterns and comparative cost of arc and incandescent units and gives some details of the installation.

105. Mason, W. A.
Street lighting in Y[illegible].
Munic. Jour. v. 38, p. 593-4. Apr. 29, 1915.
City after having estimates prepared [illegible] plant received [illegible] accepted bid [illegible] contract.

106. Installation of luminous arc lamp[illegible] Worcester.
Elec. Rev. & W. Elec'n. v. 66, p. 25-8. Jan. 2, 1915.

OPERATION, MAINTENANCE AND CONTROL

107. Nixon, H.
Maintenance of street lighting.
Illum. Engng. Soc. Trans. v. 15, p. 308-13. No. 5, 1920.
Experiences of the city of Chicago.

108. Shepherd, C. H.
Maintenance of electric lighting equipment on the Lincoln Park system.
Illum. Engng. Soc. Trans. v. 15, p. 314-20. No. 5, 1920.
Details of the installation, difficulties encountered, etc.

109. Electrically operated switchgear for street lighting control in Germany.
Elec. Wld. v. 76, p. 520. Sept. 11, 1920.
A system of electric distance control in the city of Charlottenburg which enables the operator at the central station to flood the entire city with light in a minute's time.

110. McDowell, T. D.
Simple lamp record system for street lighting circuits.
Elec. Rev. (Chgo.) v. 74, p. 668-9. Apr. 26, 1919.
Card records for noting type and history of lamps in use on large systems for street, boulevard or park lighting.

111. Shepherd, C. H.
Data on lamp operation and maintenance.
Elec. Wld. v. 73, p. 1215-16. June 7, 1919.
Records are kept which show the life of all lamps used in Lincoln Park, Chicago. Faults in supply apparatus are detected by lamp records. Data indicate that life of lamps depends greatly on switching in circuit.

112. Herz, A.
Renovation of discolored arc-lamp globes.
Elec. Wld. v. 72, p. 935-6. Nov. 16, 1918.
Illum. Engr. v. 11, p. 231. Oct., 1918. Abstract.
Glassware used in electric street lighting units deteriorates owing to discoloration. It is both difficult and expensive to replace globes, but a method of removing stain by heat treatment has been developed.

113. Mott, S. B.
Securing and operating small town street lighting.
Elec. Wld. v. 69, p. 277. Feb. 10, 1917.
General suggestions. Gives ideas on tree trimming which the manager of a system of interconnected towns found valuable in dealing with town boards.

114. Reeves, H. H.
Phantom circuit remote control.
G. E. Rev. 20, p. 884-8. Nov., 1917.

The system dealt with in this paper was assigned to provide a simple, reliable and economical means for turning on in the evening and off in the morning those groups of street incandescent lamps which are located at a distance from the central station and are fed by local transformers. The author describes the theory and operation of the system, the various component pieces of apparatus and analyzes its merits.

115. Treanor, E. D.
Operation of series incandescent lighting circuits with series transformers.
G. E. Rev. v. 20, p. 940-4. Dec., 1917.

Describes the open-circuit and short-circuit characteristics of the series transformer and shows how these have been brought into agreement with the necessary and the desirable characteristics of the series incandescent circuit. He then analyzes the combined subject of grounding, operation and protection.

116. Changing street lamps.
Elec. Wld. v. 69, p. 802. Apr. 28, 1917.

Describes a long-handled device for replacing incandescent lamps or removing bases of broken bulbs.

117. Reeves, H. H.
Incandescent street lighting regulating apparatus.
G. E. Rev. v. 19, p. 798-804. Sept., 1916.

Outlines briefly the fundamental theory of those regulators which are designed to control constant current series circuits. The effect of different kinds of loads on the regulation of the circuit and the operation of the transformer is also pointed out.

COST

118. Shepherd, C. H.
Cost problems in the lighting of public parks.
Elec. Rev. (Chgo.) v. 77, p. 389-94. Sept. 11, 1920.

Methods used in replacement of old arc-lighting equipment with type C units, improved conditions and reductions in cost resulting from change; spectacular features of Lincoln Park lighting system.

119. Analysis of street lighting costs.
Elec. Wld. v. 76, p. 637. Sept. 25, 1920.

Detail costs of one-year maintenance of 4-amp. magnetite-arc lamps and 6.6-amp. luminous arcs.

120. Cost of lighting streets at Galesburg, Ill.
Elec. Wld. v. 72, p. 600. Sept. 28, 1918.

Unit cost of installing system amounted to $197.00 for five-light clusters and $177.84 for one-light pole on system.

121. Bailey, H.
Chart for determining power costs.
Power, v. 45, p. 762-3. June 5, 1917.

An explanation of a chart for determining the cost of power for street lighting at different rates and lighting schedules.

122. Cost data on installation for lighting city streets, Lincoln, Neb.
Elec. Wld. v. 69, p. 1211. June 23, 1917.

Low-voltage series system operated with pole-type constant-current regulators.

123. Elden, L. L.
Maintenance costs of arc lamps for street lighting.
Elec. Wld. v. 68, p. 1229-30. Dec. 23, 1916.

Boston Edison Co. presents data in controversy over rates before Massachusetts Gas and Electric Light Commission.

124. Arc lamps show low-voltage record at Detroit.
Elec. Wld. v. 67, p. 546. Mar. 4, 1916.

Cost data.

125. Cost data for two styles of street lighting standards used at Riverside, Cal.
Elec. Wld. v. 68, p. 89. July 8, 1916.

CONTRACTS AND SPECIFICATIONS; FINANCE AND RATES

126. Thompson, G. L.
Street lighting with reference to the manufacturer, the central station and the municipality.
G. E. Rev. v. 21, p. 679-81. Oct. 1918.

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.

127. Methods of assessment for ornamental lighting; situation in Syracuse, N. Y.
Elec. Wld. v. 71, p. 1043-4. May 18, 1918.

A discussion of the existing situation in Syracuse, N. Y., defending the equal division between the city and the abutters.

128. Cravath, J. R.
Practical features of street lighting contracts.
Elec. Wld. v. p. 70, 709-12. Oct. 13, 1917.

Points to be observed in negotiations between municipalities and utilities, with special attention to securing and maintaining the best public relations.

129. Reed, W. E.
Street lighting specifications.
Illum. Engng. Soc. Trans. v. 12, p. 270-4; discussion, p. 274-6. No. 6, 1917.

130. West, J.
Street-lighting service and rates discussed.
Elec. Rev. & W. Elec'n. v. 70, p. 59-60. Jan. 13, 1917.

Relative importance of street lighting to total income as discussed by the Massachusetts Gas and Electric Light Commission.

131. Standard clauses for street lighting specifications.
I. E. E. Jour. v. 55, p. 522-4. July, 1917.

Report of a committee.

132. Ives, A. S.
Street lighting on cost-of-service basis.
Elec. Wld. v. 67, p. 949. Apr. 22, 1916.

Letter to editor reviewing the paper by Mr. Van Derzee, published in the *Electrical World* for April 1, 1916.

133. Van Derzee, G. W.
Street lighting on a cost-of-service basis.
Elec. Wld. v. 67, p. 758-60. Apr. 1, 1916.

Details of the indeterminate contract plan. Abstract of a paper presented before the Wisconsin Electric Association.

134. Improved form of street lighting contract in Wisconsin.
Elec. Wld. v. 68, p. 471-3. Sept. 2, 1916.

Features of indeterminate form.

135. Operating costs of Boston incandescent street lamps.
Elec. Rev. & W. Elec'n. v. 68, p. 851. May 13, 1916.

Presented by the Edison Company before the Massachusetts Gas and Electric Light Commission.

136. Street lighting by indeterminate contracts.
Elec. Rev. & West. Elec'n. v. 68, p. 801-3. May 6, 1916.

Outline of plan on the cost-of-service basis by which the municipality assumes responsibility for the operating company's special investment.

137. Street lighting contract on kilowatt-hour basis for Spencer, Mass.
Elec. Rev. & W. Elec'n. v. 68, p. 589. Apr. 1, 1916.

138. Ives, A. S.
Factors in rate making.
Elec. Wld. v. 65, p. 988-9. Apr. 17, 1915.

139. Contracts for street lighting.
Elec. Wld. v. 64, p. 1089-90. Dec. 5, 1914.

Discussion of the contract form developed by the National Electric Light Association and the Association of Edison Illuminating Companies.

140. Payment for special street lighting.
Elec. Rev. & W. Elec'n. v. 65, p. 1129-30. Dec. 12, 1914.

Methods of arranging for payment of first cost and of operating expenses in a number of cities.

STATISTICS

141. Information concerning electric lighting; tabulation.
Munic. Jour. v. 42, p. 811-24. June 21, 1917.

Based on reports from more than two hundred cities.

142. Ornamental street lighting—1916; tabulation.
Munic. Engng. v. 50, p. 155-6. April, 1916.

143. Street lighting revenues in New England districts.
Elec. Wld. v. 68, p. 1153-4. Dec. 9, 1916.

Increase in revenue has been effected despite improved efficiency of illuminants. Gives tabular analysis of street lighting practice in 110 cities.

144. Tendencies in street lighting systems. Street lighting statistics for cities over 25,000 population showing types of lamps and rates for service; tabulation.
Elec. Wld. v. 68, p. 475-8. Sept. 2, 1916.

145. Electric lighting data: station equipment amount of current used for street lighting and other purposes—fuel statistics, number and kind of lamps used for street lighting ornamental lighting rates.
Munic. Jour. v. 38, p. 884-94. June 24, 1915.

HISTORY

146. Miller, P. S.
Historical sketch of street lighting.
Illum. Engng. Soc. Trans. v. 15, p. 185-202. No. 3, 1920.
Elec. Rev. (Chgo.) v. 76, p. 770-1. Mar. 8, 1920. Abstract.

Includes a list of thirty references.

The following historical dates will be of interest:

1808 Sir Humphrey Davy produced the electric arc.
1831 Faraday established the connection between electricity and magnetism and laid the foundation for the modern electric machine.
1843 Foucault improved upon Davy's charcoal electrode by employing graphite pencils made from carbon deposited upon the sides of gas retort.
1845 Electromagnet was invented by Wheatstone and by Cooke.
1870 The electric machine brought to a stage of practicability by Gramme and others.
1878 During the Universal Exhibition in Paris the Place and Avenue de l'Opera were lighted by Jablochkoff candles.
1878 Brush invented the series arc lamp with regulating shunt coil.
1879 Brush developed the double "all night burning lamp."
1879 Edison made the first successful incandescent lamps.
1879 First public street lighting by arc lamps in this country in the Public Square of Cleveland, Ohio.
1894 The enclosed carbon arc lamp was perfected.
1904 The Gem lamp was introduced.
1905 The first ornamental street lighting system was installed on Broadway, Los Angeles.
1905 The tantalum lamp was brought out.
1906 Flame carbon arc lamps were placed on the market.
1909 The tungsten filament lamp began to displace the carbon lamp.
1911 The first real "white way" was lighted in New Haven, Conn.
1914 The vacuum tungsten began to yield leading place to the nitrogen-filled Mazda C lamp.
1916 The first installation of the so-called "intensive lighting" was made in San Francisco on Market Street and known as the "Path of Gold."

REFERENCE LISTS

147. Illumination bibliography.
Illum. Engng. Soc. Trans. v. 15, p. 385-91. No. 7, 1920.

A classified analysis of all the available books in English, pertaining to illuminating engineering.

148. Mitchel, Alma C.
List of references on street lighting.
Special Libraries. v. 10, p. 24-7. Jan., 1919.

List of 139 references arranged in one alphabet; includes some material on gas lighting.

149. Illuminating Engineering Society.
Report of the Committee on Progress.

Annual report reviewing the entire field of illumination and citing numerous references. The report is published in the Transactions of the Society. The amount of material in each of the recent volumes devoted to street lighting is shown below.

v. 8, p. 348-52. 1913.
v. 9, p. 532-37. 1914.
v. 10, p. 537-43. 1915.
v. 11, p. 728-34. 1916.
v. 12, p. 372-80. 1917.
v. 13, p. 473-78. 1918.
v. 14, p. 343-49. 1919.
v. 15, p. 448-56. 1920.

150. Bohle, Hermann
Electrical photometry and illumination, 222 p. 1912. Charles Griffin & Co., London.

Includes an extensive bibliography on electric lighting. References to street lighting are found on p. 217-18.

GEOGRAPHIC AND AUTHOR INDEX

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Balancing

Four Years of Balancing Practice. Akimoff, N. W.
Am. Soc. Nav. Engrs. Jour., May, 1921; v. 33, pp. 261-267.
(Illustrated article on the general principles.)

Circuit Breakers

A Measure of the Current-Breaking Capacity of Oil Circuit Breakers. Charpentier, P. (In French.)
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Elec. Wld., May 28, 1921; v. 77, pp. 1235-1237.
(Short article showing results obtained at the Cedar Rapids plant of the Iowa Railway & Light Co. Includes tabulated data on other automatic plants.)

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(Tests results are presented in tabulated and graphic form.)

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(Detailed discussion, with special emphasis on the electrode type. Describes some typical installations and gives a list of recent users of such boilers.)

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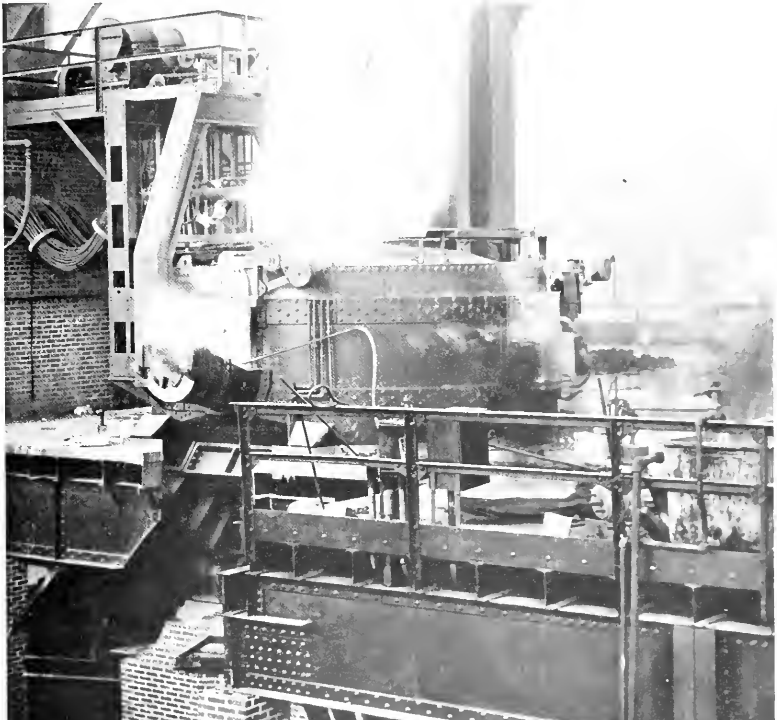

FORTY-TON HEROULT STEEL FURNACE AT THE CHARLESTON, W. VA., NAVAL ORDNANCE PLANT

(See article, "The Largest Electric Steel Furnaces," page 833)

GENERAL ELECTRIC REVIEW

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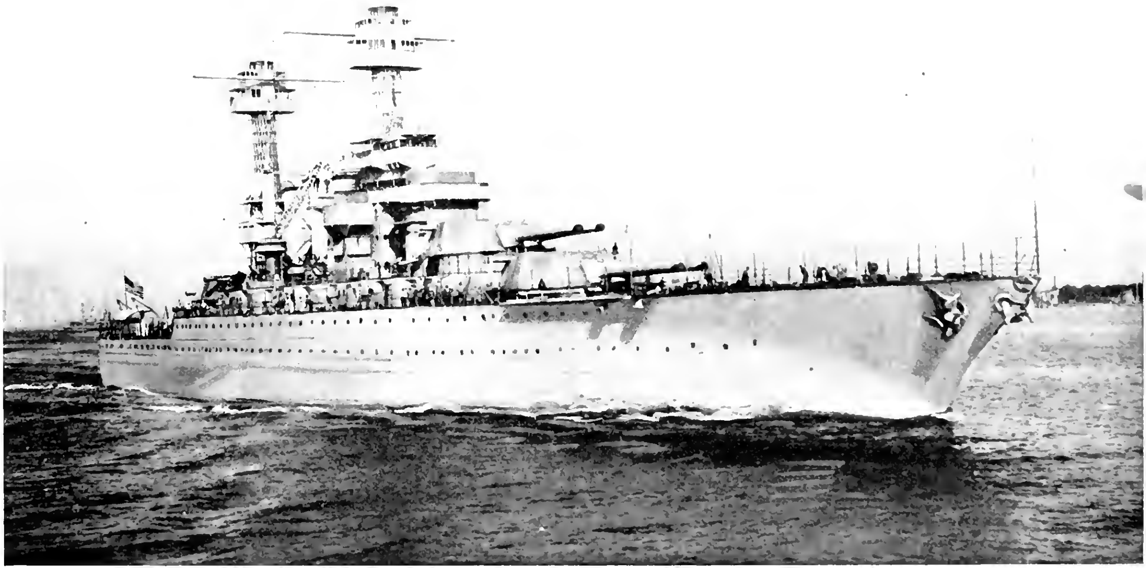


U. S. BATTLESHIP *MARYLAND*

The Third "All-electric" Dreadnaught Completed for the U. S. Navy

Main battery, eight 16-inch guns; displacement, 33,000 tons; speed, 21 knots; length, 624 ft.; beam, 97½ ft.

GENERAL ELECTRIC REVIEW

THE ELECTRIC PROPULSION OF SHIPS

A brief account is given in this issue of the trials of the "All Electric" U.S. Battleship *Maryland* and in a previous issue (April, 1919) we dealt at length with the *New Mexico* and her equipment, so on this occasion little comment is needed on the *Maryland's* equipment. But appended to the article in our present number is a list of electrically propelled ships, both those built and being built for the U. S. Navy and the Merchant Marine. This is a truly imposing list and is worthy of special note.

Every intelligent citizen in every country today is interested in battleships, but the main interest is in the limitation of armaments and the corresponding reduction of taxation which is one of the most pressing problems of all those sorely tried governments and peoples who took part in the World War. For this reason, some of the ships listed as being built may never be completed or, at least, not completed and commissioned according to present schedules.

But whether these ships are completed according to programs or not, the engineering and commercial world should remember one lesson that this list teaches, namely, that electric propulsion for ships has been tried, proved effective, and practically speaking, standardized, for one of the most powerful navies in the world. As a nation's life is dependent upon her naval defense, it is but natural that the best expert advice and judgment should be used in selecting the propelling equipment for her battleships and, therefore, this selection of electric propulsion for the most powerful, the most modern and the most important units of the U.S. Navy is the greatest possible tribute to the electrical equipment for ships in regard to their most essential features, namely, reliability, weight and space occupied as well as to its economy.

The *New Mexico* and the *Maryland* are ships of moderate power as ships go today but their more powerful sister ships the *Dakota*, *Indiana*, *Montana*, *North Carolina*, *Iowa* and the *Massachusetts*, each with a horse power just double that of the *Maryland*, namely, each with 60 000 horse power, are all scheduled to be equipped with electric drive. And over and above this the six battle cruisers of the *Lexington* class, each with the enormous power of 180,000 horse power and each designed for a speed of 33.6 knots, are scheduled to be "all electric" ships.

The adoption of electric propulsion for every unit in such a gigantic naval program, so soon after the inception of the "All Electric" Ship is, we believe the greatest triumph for an engineering principle that has ever occurred in the history of engineering. It is also a great triumph for the pioneers and sponsors of electrically propelled ships.

So far as the U.S. Navy is concerned, electric propulsion reigns supreme, but, on reviewing the general subject of ship propulsion, it will be noted that there are many factors in the operation of fighting ships that can take advantage of the inherent characteristics of the electric drive, such as the maintenance of enormous power for high speeds and the economical use of fuel at cruising speeds, also the subdivision of the power and motor units in such a way as to enable different classes of service to be performed economically with the same apparatus. But, where these requirements are not present, such for instance as in a passenger ship or tramp steamer, will electric propulsion displace the older form of equipment in use? That is the question. The answer is not likely to be given immediately, but a study of the situation leads us to the conclusion that although many of the refinements possible with electric drive are not needed in merchant ships and especially not in the tramp steamer, the economies to be secured by using rotary prime movers will ultimately lead to the electric drive for ships becoming universal.

The advantageous arrangement of all the apparatus, the elimination of the shaft alley and the reduction of fuel used, all lead to space economy with electric drive and accordingly give an increased cargo carrying capacity. Records show that the electric apparatus is less liable to interruption of service, and also show that when accidents do occur they are more readily repaired in the case of electric drive. Even in the event of serious damage the apparatus can be reconnected, with comparatively little trouble, in such a way as to make a large percentage of the original power capacity available at the propeller.

If the economies incident to the high speed turbine with its good steam and water rates are to be secured for marine propulsion, some of its inherent disadvantages such as the reversal of the moving elements, speeds in excess of economical propeller speeds, or the provision of some means of speed reduction between the prime mover and propeller shaft, must be overcome. At present electric propulsion can overcome all these difficulties in an absolutely satisfactory way so far as technical considerations go. When we have reached this stage, how long will it be before refinements in design, standardization of parts for definite ranges of size, etc., will lead to electric propulsion displacing all other modes of propulsion on the sea?

The history of electricity in the industries has been, almost without exception, that where the electric drive has been tried it has displaced all older methods. The difficulties to be overcome in marine engineering are no greater than those that had to be mastered in many other fields of engineering. Electric energy can be controlled more perfectly and more efficiently than any other form of energy and we confidently look for its inherent characteristics to lead to economies on the sea as they have led to economies on the land.

But if these economies are to be secured, we must overcome the common prejudices which persist in considering electrical apparatus and electrical connections complicated—experience in the industries has proved electrical apparatus to be more simple, more reliable and more easily repairable than mechanical apparatus.

We quote the concluding paragraph of an article by Mr. W. L. R. Emmet on "The Electric Propulsion of Merchant Ships," published in our issue of January, 1920, to emphasize that experience has taught that the operating force can make repairs in electrical apparatus more readily than in mechanical apparatus.

"The history of the electrical industry has repeatedly shown that persons who have not used electrical apparatus assume that its operation requires a high order of skill and expert knowledge, and of this assumption we have already heard much in connection with electric drive for ships. A vast amount of experience has repeatedly shown that this assumption is the direct reverse of the truth, and a little thought as to the conditions in electrical apparatus should make the reason obvious. Conductor circuits are much simpler mechanically than pipes and mechanical motions, and electrical machinery is simply a combination of electric circuits with motion of rotation. The connections are easily shown by diagrams, and little mechanical skill is required to make them. The work of insulation can be so done that, under such conditions as exist in ship installations troubles which might involve difficulty of repair by unskilled persons are very improbable. In all the extensive uses of electricity in mills, mines, railways, and other industries it has seldom failed to become popular immediately with the operating forces. In no case has this been more marked than in the ships which have been driven electrically. Large electrical apparatus is generally simpler than small, and the machinery used to propel a ship is in many respects simpler than that which is used to light it. Instead of introducing difficulties to the operating force, the adoption of electric drive will eliminate them and make ships much less dependent upon the skill and resourcefulness in their crews."

J. R. H.

The U.S.S. *Maryland*

By C. D. Wagoner

Publication Bureau, General Electric Company

We are pleased to give our readers some details of the latest U.S. battleship. The U.S.S. *Maryland*, like the U.S.S. *New Mexico*, which has been so conspicuously successful, is an "all electric" ship. She came through her builders' trials with flying colors and great things are expected of her on her official government trials, which are to take place in November.—Editor.

Capt. Charles F. Preston, in Command of the U. S. S. *Maryland*

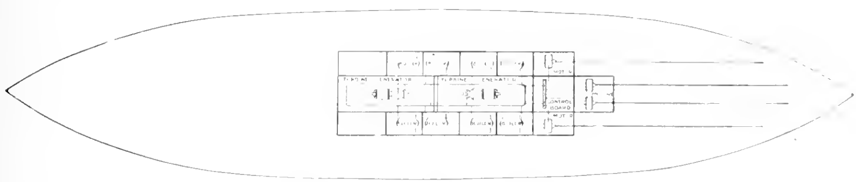
The U.S.S. *Maryland*, the third electrically propelled battleship of the U. S. Navy to be completed, will put to sea for her official government trials in the early part of November. This electric superdreadnaught is the latest achievement of American naval architects and her propelling machinery is the latest triumph of the electrical world.

The *Maryland* is the first American battleship to carry 16-inch guns, her main battery consisting of eight 16-inch rifles. There are two turrets forward and two aft, each mounting two guns, each of which is 57 feet in length. Each gun fires a shell of 2100 pounds for a distance of 20 miles, using a charge of approximately 480 pounds of powder. Her secondary battery consists of fourteen 5-inch guns, for use against mosquito craft, and she carries four 3-inch anti-aircraft guns, a 3-inch landing gun and six .30-calibre machine guns. She has two underwater torpedo tubes for 21-inch torpedoes.

The *Maryland* displaces 33,000 tons, has a speed of 21 knots, and a cruising radius of 10,000 miles. She is an oil burning ship with a fuel capacity of approximately 1,400,000 gallons. Her length is 624 feet and her beam 97½ feet.

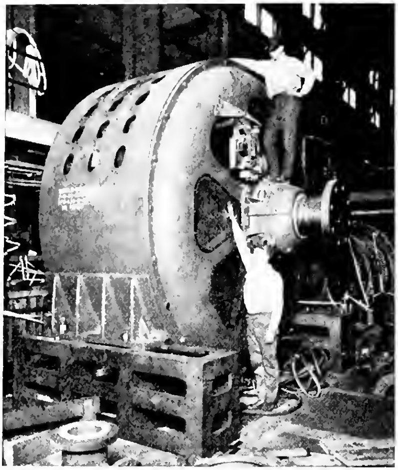
Such, in brief, is the specification of this latest "Pride of the Seas" who recently completed her builders' trials with a perfect record. For 33 continuous hours at sea, off the Virginia Capes, she was put through all sorts of tests, bringing into play the greatest stress on all parts of her machinery and equipment, but not the slightest trouble was experienced. In fact naval officials declared she operated more like a boat that had been in service four or five years, so readily and easily did she respond to the tests.

Captain Charles F. Preston, who has been assigned the command of the *Maryland* and was aboard during the preliminary trials, is most enthusiastic over the perfect performance of the new electric ship. "I have never been on a warship that pleased me more in my thirty-six years with the navy. She's a wonder in every respect, the best warship in our navy and the most powerful in the world," he declared, "I am highly pleased and satisfied with her electric equipment. There is practically no vibration and sometimes I actually looked out to sea to learn if



General Arrangement of Machinery on *Maryland* we were under power, so quietly and smoothly did her machinery operate."

Like her prototype, the *New Mexico*, pioneer electric warship of the world, the *Maryland* is electrical throughout. Her main propulsion machinery consists of two Curtis steam turbine-generators, each designed to develop 11,000 kilowatts at a speed of 2030 revolutions per minute to drive the ship at a speed of 21 knots. These supply power to four 7000-horse power General Electric induction motors,



One of the Propeller Motors. The *Maryland* has four such induction motors each of 7000 h.p. and 170 r.p.m. The motor is 12 ft. in diameter and weighs 62 tons

directly connected to the four propeller shafts and turning at 170 revolutions per minute. The motors, among the largest ever built, are 12 feet in diameter, weigh 62 tons, and the 28,000 horse power thus available for propulsion purposes is enough to supply power to a city of 100,000 population.

The two turbine-generators, supplied with steam generated by eight oil burning boilers, can be run independently. Either is capable of driving the ship up to a speed of about 17 knots. The power generated by them is used for no other purpose than propelling, electrical current for other needs being generated by six 300-kilowatt turbine-generators.

Virtually every electrical appliance used afloat and ashore has been installed in this new battleship. The electrical equipment includes radio telegraph, loud speaking telephones, ordinary telephones, gyroscope compass, steering gear, anchor windlass, capstan, boat cranes, winches, air compressors, air heaters, turret training, turret gun elevating, ammunition hoists, gun firing, range signalling, powder testing oven, deck fans, ice machines, laundry equipment, carpenter shop, lighting, visual signals, motion pictures, sterilizer in operating room, potato peeler, ice cream freezer and other kitchen utensils, bake ovens, irons for laundry and tailor, storage batteries, motor boat ignition, etc.

It is probable that no ship built by any nation in the past has been so thoroughly equipped for the comfort and convenience of the crew.

A completely equipped hospital will be maintained on board with naval surgeons to look after the health of the crew and a dentist to look after the men's teeth. A chaplain will be assigned to the ship to hold regular church services and to devote his time to the spiritual welfare of the officers and men.

The *Maryland* was built by the Newport News Shipbuilding and Dry Dock Company and the electrical equipment was designed and manufactured by the General Electric Company.

The ship was launched on March 20, 1920. Her chief characteristics are:

Length	624 feet
Beam	97½ feet
Draft	30½ feet
Weight	33,000 tons
Speed	21 knots
Number of propellers	4
Shaft horse power	28,000
Oil capacity	1,400,000 gallons
Oil burning boilers	8

Four more battleships of this type are being built, the *California* to be completed this summer, the *West Virginia* to be ready for her trial trips in 1922, the *Colorado* and the *Washington*. In addition the navy is building six 43,000-ton, 60,000-horse power battleships and six battle cruisers rated at 180,000 horse power each, or six times as powerful as the *Maryland*. Both of these types of warship will carry 16-inch guns and will be electrically driven.

Production of the electrical machinery for several of these vessels is now progressing under the direction of W. L. R. Emmet, consulting engineer of the General Electric Company, who advocated the principles of the electric drive as long ago as 1909, was instrumental in its adoption by the government, and designed the first electric drive installed by the navy on a battleship, now working so successfully on the U.S.S. *New Mexico.*

Some idea of the popularity and growth of electrically propelled ships in both the U. S. Navy and the American Merchant Marine may be gained from the figures given in the appended table of electrically propelled ships already completed and in service, and those under construction.

Ship	Type	Horse Power	Speed Knots	Tonnage Displacement
		Naval Vessels		
In Service				
Jupiter	Collier	7,000	15	20,000
New Mexico	Battleship	28,000	21	33,000
Tennessee	Battleship	28,000	21	33,000
Being Built				
California	Battleship	28,000	21	33,000
Colorado	Battleship	28,000	21	33,000
Maryland	Battleship	28,000	21	33,000
Washington	Battleship	28,000	21	33,000
West Virginia	Battleship	28,000	21	33,000
Dakota	Battleship	60,000	23	43,000
Indiana	Battleship	60,000	23	43,000
Montana	Battleship	60,000	23	43,000
North Carolina	Battleship	60,000	23	43,000
Iowa	Battleship	60,000	23	43,000
Massachusetts	Battleship	60,000	23	43,000
Lexington	Battle Cruiser	180,000	33.6	43,500
Constellation	Battle Cruiser	180,000	33.6	43,500
Saratoga	Battle Cruiser	180,000	33.6	43,500
Ranger	Battle Cruiser	180,000	33.6	43,500
Constitution	Battle Cruiser	180,000	33.6	43,500
United States	Battle Cruiser	180,000	33.6	43,500
		Merchant Ships		
In Service				
Eclipse	Cargo Carrier	3,000	11	16,000
Invincible	Cargo Carrier	3,000	11	16,000
Archer	Cargo Carrier	3,000	11	16,000
Independence	Cargo Carrier	3,000	11	16,000
Cuba	Passenger and Cargo	3,000	17	3,580
Mariner (Diesel-electric)	Trawler	400	10	500
Being Built or Equipped				
Eight cargo carriers, each		3,000	11	16,000
Four coast guard cutters, each		2,600	16	1,600
Fordonian (Diesel-electric)	Cargo Carrier	850	9	2,200

Total displacement tonnage, naval and merchant marine, in service, 154,080; being built, 820,600

Turbine Lubrication*

PART II. MARINE TURBINES, REDUCTION GEARS AND LUBRICATING SYSTEMS

Part I of this article, published in our July issue, dealt with the lubrication of steam turbine bearings for stationary land installations. The present installment discusses the lubrication of reduction gears with special reference to marine outfits and describes at length the various lubrication systems that are in common use. The most important factor in any lubrication problem is the oil itself; and in steam turbine lubrication where the conditions are extremely severe the use of oil having the correct characteristics is doubly important. The specifications of a satisfactory oil for steam turbine bearing service were given in Part I, and they are modified here to correspond with the requirements of gear service.—EDITOR.

In the large majority of stationary outfits on land, steam turbines are used to drive electrical generators from which the power is distributed to various operating machines about the plant or in neighboring plants. As previously stated the speed of the steam turbine must necessarily be high, but as an electric generator can easily be so designed that its speed conforms to that found most efficient for the turbine, it can be directly connected to the turbine. With marine outfits, however, it is impossible to design a propeller which will run economically at the high speed of the turbine. This is compromised in the case of some speed boats by running the turbine under speed and the propeller over speed. This procedure, however, is quite uneconomical. The problem then is to transmit the power generated by the turbine at high speed to the propeller which must rotate at comparatively low speed. Three methods in general have been used to carry out this transmission of power: First, hydraulic; second, electrical; and third, mechanical.

(1) The hydraulic method utilizes a high speed pump upon the turbine shaft, and a low speed hydraulic turbine upon the propeller shaft. Several outfits have been constructed and operated on this principle, but even with the best designs the efficiency was found to be low and the method has not received general application. (2) The electrical drive is perhaps the most widely discussed method of power transmission on ships at the present time, and many very large ships have been successfully operated on this system. It consists, primarily, of a high speed generator directly connected to the turbine. The electrical power that is thus generated is utilized in driving a low speed motor connected to the propeller shaft. This system is quite elastic. (3) At the present time the most generally used system of power transmission for ships is the mechanical drive using reduction geared apparatus.

Reduction Gears

Reduction gears used with turbine outfits may be either single or double reduction. In the single reduction outfits a small pinion attached to the turbine shaft drives a large gear connected to the propeller shaft. In the double reduction gears the small pinion on the turbine drives a larger pinion on the counter-shaft to which is attached a smaller pinion which in turn drives a large gear on the propeller shaft. This latter system is applicable where large reduction speeds are required. A characteristic ratio of speeds used is 3,500 r.p.m. on the high speed shaft, 500 r.p.m. on the intermediate, and 100 r.p.m. on the low speed shaft. The gears used in this reduction apparatus are usually constructed with the herringbone type of teeth to prevent end movement, though recently there has been some agitation for straight toothed gears.

As the tooth clearances in reduction gears are very small, sometimes not over 1/1000 of an inch, the bearing supports must be rigid in order to eliminate changes in alignment due to heat expansions or binding stresses. The clearances in the bearing boxes also must be small and the same throughout, about 2/1000 inches, and the babbitted bearing pieces must be constructed with great accuracy in order that the system may run true with minimum binding. The lubrication of these bearings is the same as previously discussed under the main turbine bearings. It is sometimes thought advisable to install a more or less flexible coupling on the turbine shaft between the turbine proper and the small pinion of the reduction gear. This allows the gear to take its own alignment without undue strain, but this should be in the nature of an extra precaution and not a necessity. The alignment should be correct without the flexible coupling.

The use of reduction gears introduces a new problem in the lubricating system. These gears have tooth pressures, running from 300-750 pounds per square inch, and in

*Courtesy The Texas Company

order to run smoothly and without wear should be lubricated. Too low a viscosity oil will not withstand these high pressures and will not prevent wear on the tooth surface. In any gear there is a slight slipping in the meshing action and the lubricant should prevent or reduce the degree of metallic contact of these surfaces. It is generally considered desirable to supply a different lubricant to the gears from that supplied to the bearings, but in many cases this is found impractical and the gears are supplied from the same lubrication system as the bearings. This means that the oil used in the general system must be of sufficient viscosity at the temperature at which it is supplied to the gears to withstand the high tooth pressures and prevent wear. Oils of 300-500 seconds viscosity at 100 deg. F. have been found to operate quite satisfactorily on the gears. On very slow running gears which normally have higher tooth pressures an oil with a viscosity of even higher than 500 seconds is often recommended.

But oils of these high viscosities will not operate satisfactorily in bearings, and therefore some compromise must be made to get the best all-round lubrication. As the viscosity of oils decreases with temperature rise, some operators reduce the viscosity of the oil for their bearings by heating that portion of the oil which goes to the bearings, while that which goes to the gears remains at normal temperature. If the temperature can be controlled this is a solution to the problem.

The oil is applied to the gears by means of a number of spray jets so arranged that the oil is forcibly played upon both the entrance and exit faces of the teeth as they mesh. The excess of oil is drained away to the oil sump.

There has been considerable discussion as to the cause of pitting of the gear in reduction gear apparatus. For a while attempts were made to lay the blame upon the oil, but it is generally conceded now that the action is due to the flaking off of small particles of metal as a result of the localized tooth pressures before wearing in properly. This action does not continue appreciably after a short time. Another trouble found in reduction gears is occasional rusting. This is no doubt due to the combined action of moisture and air in the oil, i. e., emulsions, as in this form moisture and air are brought into intimate contact with the steel, and the possibilities of rusting are greatly accentuated. The remedy naturally is to use oil with a minimum tendency towards emulsion and to keep it in good condition by removing such emulsions as unavoidably occur.

Lubrication Systems

It is therefore evident that steam turbines should be equipped with the most efficient lubrication system. Large quantities of oil are necessary which may become mixed with water or air, and due to the high temperature may slowly change in structure. While this so-called breaking down place takes in only a very small proportion of the total oil used it may be of such a nature as to affect the whole body of the oil and impair its lubricating qualities. Water, dirt, sludge, and gum due to the decomposition of the oil therefore must be removed. This result can be accomplished in several ways and there are a number of systems designed for the purpose, which systems vary according to size and type of turbine, quantity of oil used and temperature and viscosity of oil required. Each system, however, must have a storage tank, a positive means for delivering oil to bearings, a means for cooling the oil to the required temperature, and some method of removing objectionable material. In small turbines the essentials are combined by allowing the oil to drain into a sump tank which is of ample capacity to allow the oil to remain in practical quiet sufficiently long for the sludge to settle out, which action will take place provided the oil was originally of the proper character. Unfortunately the sump tanks of many small turbines are of insufficient capacity to allow this settling to take place satisfactorily. It is usual to have cooling coils placed in this tank in order to reduce the temperature of the oil to that required for the bearings. In order not to disturb the sediment the oil is drained from the tank several inches above the bottom by means of a pump geared directly to the turbine shaft, and pumped to the bearings under pressure.

In larger turbine sets, more elaborate systems are used for reconditioning the oil, differing considerably in details but more or less the same in principle. In each of these systems there are storage tanks, sump tanks, cooling coils, strainers, filters, with the necessary pumps to carry the oil from one stage to another. Some systems in addition have special tanks where the oil can be heated, and thus expedite the settling out of the sludge. Whatever the type of system used it must be positive in action, as simple as practical to construct and contain sufficient safeguards to assure an adequate supply of oil at all times to the bearings and gears. This necessitates many parts being in duplicate and relief valves being placed so as to allow by-passing of the oil around strainers and filters if they become clogged.

Pressure and Gravity Systems

In order to force the oil through the lubricating train there are in general two systems—the pressure and the gravity. From the standpoint of first cost, the pressure system is the cheaper, due to the fact that less equipment is required, such as tanks, pipe, fittings, etc. In operating the pressure system, the lubricating oil pumps draw the oil from the sump or drain tank, or purifying system, and apply the oil to the unit under pressure, the oil draining back to the drain tank where it is again picked up by the pumps and again applied to the unit. This causes a continual circulation of the oil through the system. At the present time there are a number of units operating under the pressure system with approximately 400 gallons of lubricating oil in the system. This condition is usually wrong, as the circulation of the oil is so rapid that after coming in contact with heated surfaces in passing over the bearings it does not have time to settle and cool and will deteriorate very rapidly. In operating under the pressure system, it should be of ample size to handle from 800 to 1,000 gallons of oil in continuous circulation. The pressure system should pump oil to the bearings in excess of that required, a relief valve or other means being provided to drain the excess oil back to the sump tank.

The gravity lubricating system is handled somewhat differently from the pressure system. The oil is taken from the drain tank by the lubricating oil pumps and delivered through the purifying system to a gravity tank located in the top of the engine room. From here the oil flows over the unit by gravity. The pressure obtained depends on the height at which the gravity tank is located above the unit. It is often found desirable to have two tanks in the gravity system. This allows sufficient time for the oil to settle and for the sludge and emulsion to be eliminated. It also provides a duplicate so that the tanks may be cleaned alternately.

With the gravity system, improvement can be made over some of the present types of gravity tanks in use. There is one type of gravity system in which the lubricating oil pumps are controlled by a float in the tank which automatically closes and opens the steam control on the throttle valve of the lubricating oil pump. By this method a high and low level of oil is obtained in the gravity tank. When the high level is reached the float automatically closes the steam valve which slows down the lubricating oil pump and decreases the oil discharge from the pump. When the low level is reached, the float will automatically open the steam valve and allow the lubricating oil pump to speed up, increasing the discharge of oil from the drain tank to the gravity tank. When operating under these conditions where lubricating oil pumps are governed by automatic control valves, a by-pass throttle valve should be installed for operation in case the automatic control valve becomes stuck from corrosion or mechanical defects. The automatic control valve when installed should be equipped with union or flanged connections and a valve on each side, so that the operator can make any necessary repairs in the shortest time and most convenient way.

With this type of gravity system the oil is not agitated to the same extent as with the system where lubricating pumps are operating continuously at a set speed. This system also allows the oil to rid itself of any air that has accumulated which would cause a drop in pressure if an excessive air emulsion were formed. This emulsion takes place especially with some types of oil of high viscosity.

In some installations visible and audible alarms are used to indicate when the oil in the tanks is at its high and low levels.

The other type of gravity system is arranged in a similar way with the exception that the pump works under the control of an automatic valve, so that it pumps continually at the same rate of speed after the system has been put in operation, working under steaming conditions. This causes the overflow from the gravity tank to drain tank to be operating at all times.

The lubricating oil system for marine practice should be a combination of both pressure and gravity types. This can be arranged by putting in a by-pass from the discharge side of the lubricating oil pumps to the main supply line from the gravity tank. With valves installed at the proper points either system can be operated independently.

The gravity tank should be of sufficient size to have at least four division plates with the discharge from the lubricating oil pumps striking a baffle plate installed in the first compartment. This will allow the force of the oil to be broken before it flows into the compartment, after which the oil flows successively under the first division plate, over the top of the second, under the bottom of the third, and over the top of the fourth division plate into the last compartment. Thence it flows into the main feed or supply line to the unit. The main supply line should be connected to the side of the gravity tank at least 6 inches from the bottom of the tank, in order that any sediment in the oil will have a tendency to settle at the bottom instead of flowing down the supply line and passing into the unit. All gravity tanks should be equipped as mentioned in order to eliminate the air from the oil as much as possible. Air will hasten oxidation and quicken the rise in the viscosity of the oil. The gravity tank should be equipped with a vent pipe on each compartment to allow air to escape, as the cover on top of the tank is bolted down tight to prevent oil from escaping when the ship is rolling and pitching at sea. The tank should also be equipped with coils for heating the oil in cold weather, or at such time as the oils need reconditioning. An overflow line should be fitted to the last compartment approximately 6 to 8 inches from the top of the tank, this line leading back to the sump tank. At the lower engine room platform there should be installed in this line a sight glass which will enable the engineer to note the amount of oil in the system. On the last compartment of the gravity tank there should be fitted a sight glass equipped with automatic valves, so that in case the glass becomes broken the pressure of the oil will close the valve. Each compartment should be equipped at the lowest point with a valve for the purpose of draining off water which may accumulate in this tank. This drain should be so installed that it will discharge into a funnel fitted on the drain line, which will lead to the bilge. The gravity tank should not be installed at an excessive height, as greater stress will be thrown on the oil pump in forcing the oil to the tank, while if the tank is too low the proper pressure cannot be maintained for operating the gravity system. The proper height should range from 20 to 30 feet above the center line of the main unit. The tanks usually have a capacity of approximately 1,000 gallons. A float should be installed, electrically connected, that will ring an alarm bell to attract attention should the oil level become low.

Pumps and Strainers

Lubricating oil pumps should be installed as low as practical in order that the oil either will flow to the pump or the vacuum lift will not be very great. The pumps should be installed in duplicate so that they may be used alternately, and should be of sufficient size as to be capable of handling a slight excess quantity of oil over that usually needed for proper lubrication. The pumps may be either of the rotary gear type or reciprocating, and may be direct connected to the unit or operate independently of it. The rotary pumps are simpler in operation, but if run at too high speed they may churn the oil and form emulsions. This type of pump, driven by small steam turbines, has been found quite efficient, especially in large units. Reciprocating pumps may be either horizontal or vertical, but the latter type, especially for marine use, is generally considered preferable. Many installations make provision for automatically governing the speed of the pump, instead of controlling it by direct connection to the turbine. In pump installation it is often found advisable to install a pressure gauge and a relief valve at the discharge side of the pump, so arranged that the excess oil is led back either to the sump tank or to the suction end of the pump. This is for the purpose of providing safety to the entire lubricating system, for should an excessive pressure develop the valve will open and relieve the pump of this pressure. In the case of reversing turbines, pumps are sometimes so equipped with check valves that they will operate in either direction. In all pump installations no soft or composition packing should be used, as under the action of the oil this packing may deteriorate and impair the quality of the lubricant.

In all lubrication systems there are installed strainers equipped with very fine mesh wire for eliminating any particles which may have accidentally got into the system. These are usually installed on the discharge side of the oil pump and are in duplicate. Many systems of lubrication also have strainers installed in other places. The strainers should have a large ratio of their area to that of the pipe—at least 6 to 1—and should require a low pressure head to overcome the friction of the oil through them. It is advisable to have strainers equipped with a relief valve or other means of overflow, so that if they become choked the flow of oil through the system will not be checked.

Oil Coolers

In many lubricating systems of steam turbines, especially in the smaller units where there are no filtering systems, it is necessary that the oil which comes from the bearings and gears at a high temperature should be cooled, so that it goes back to the bearings at the proper temperature. In many small units cooling coils are placed in the sump tank, but in the larger units it is generally found more practical to pass the oil through a separate cooling tank especially designed for the purpose. By this means cooling coils may be relieved of vibrations, and can be inspected more easily than if they were placed in the sump tank in the base of the unit. Oil coolers are generally built like steam condensers but must be equipped with baffle plates in order that the stream line flow of the viscous oil will be broken up, and the oil caused to come more completely in contact with the cooling surface. In oil coolers the pressure of the oil should be greater than that of the water so that in case of a leak, water will not be forced into the oil. It is advisable to pump the water through the cooler and not allow it to flow through by gravity, as this gives the engineer a more positive control of the water flow. Thermometers should be placed both in the inlet water line and the outlet oil line. In cold weather the oil cooler may often be by-passed.

Sump, Settling and Reserve Tanks

All lubricating systems are provided with sump tanks which are generally placed at the lowest point in the system, with the possible exception of the lubricating oil pump. In some systems the sump tank may act as a settling tank but generally the settling is done in a separate unit. The sump tank should be of ample capacity to contain approximately the entire quantity of oil used in the system, and should be equipped with vent pipes and float so that the amount of oil present can be noted by the engineer. A drain should be installed at the lowest point, and the suction line to the lubricating pump should take the oil from a point at least two inches above the bottom so that foreign particles will not be drawn into the system.

From the sump tank the oil is usually pumped to the settling tanks. These should be of ample size to hold the entire charge of oil in the lubricating system, and should be equipped with steam coils, drains, vent pipes, sight glasses, and various by-passes and cross-connections. By having the settling tanks large, the oil remains comparatively quiet, and if the oil is heated, water, emulsions and sludge will very largely separate out. Some engineers advise that sump and settling tanks be equipped with water legs so that the water and sludge which separate out will not be mixed with the mass of oil by the motion of the ship. Settling tanks may be installed in duplicate, which allows one tank to act as a reserve in case the other is out of commission for cleaning or repairs. In many cases, however, it is considered advisable to have a special tank for the reserve oil.

Filters and Cleaners

Most of the larger installations and many of the smaller ones in addition to the settling tanks provide filtering or cleaning units for reconditioning the oil and removing any harmful products of decomposition. In the filtering systems the oil is passed through cloths which remove such material as was not removed by the strainers and settling tanks. Filters are usually composed of a number of small units so arranged in a tank that they can be taken out one at a time and cleaned without disturbing the flow of oil through the filter. The settling tank and filter may be combined in one unit and in some cases, especially if a pressure system is used the filter unit may also contain the supply tank.

Instead of filters many systems separate the oil from water and sludge by means of centrifugal units. As the impurities in the oil are generally heavier than the oil itself, they are thrown to the outside of the centrifuge and can be drawn off. These centrifuges are so designed that there is no loss of oil and even if the amount of water and sludge is very small, the oil cannot get into the drain line provided for the impurities.

It is not generally considered necessary to cause all the oil, as it comes from the turbine, to pass through the filtering or cleaning system on each cycle. In some systems a batch of oil is withdrawn at one time, treated and then returned to the system, while in others the pipes are so arranged that about 5 per cent or 10 per cent of the oil is continuously withdrawn, is passed through the filters or cleaners and then returned to the system. If the oil is of proper character to begin with, these partial systems are found to be quite efficient, and the oil is kept in service a long time by their use.

Piping

All piping should be so installed and equipped with valves that any of the duplicate units in the lubricating system can be by-passed or cross-connected if necessary or desirable. The oil filling line in the case of marine outfits should be fitted with a water-tight cap, and care should be taken that no other oil but turbine oil is admitted to this line, as any marine engine oil or cylinder oil becoming mixed with the turbine oil will so change its character that it will be unsuitable for turbine use, and may cause trouble throughout the system. Gauges, indicators, alarms, thermometers, etc., should be installed so that the engineer may know at any time the amount of oil in his supply tank, and also whether the pumps, strainers, and filters are operating efficiently or not. The piping should be installed with as few sharp bends as practical, especially on the line leading from the gravity tank or pressure pump to the bearings or gears. Gate valves are usually preferred to globe valves, as there is less loss in friction when the oil passes through them. In cleaning oiling systems waste should not be used as the fine lint, which it is impossible to prevent adhering to the surface, will clog the strainers and cause considerable trouble.

Governors

The steam supply to many steam turbine outfits is controlled by means of oil operated governors and valves. The oil is usually furnished to the governors at a considerably higher pressure than should be used in the bearings or reduction gears, especially the former. Some installations take care of this by having a separate oil pump for the governor gear. Others use the same pump but pass the oil to the bearings through reducing valves. On account of the small passages incident to the throttling action, considerable care must be taken to keep the viscosity and consistency of the oil for the governors at a constant value. It is evident, therefore, that the temperature of the oil must not vary and that the oil must be free from emulsions and sludge; otherwise the governing action will be erratic. This again emphasizes the importance of removing all sludge and emulsions from the lubricating oil in order to have the turbine operate efficiently.

When gears are used it is advisable, if practical, to have them lubricated by a separate system from that used to distribute oil to the bearings, as the gears on account of their high tooth pressure require a much more viscous oil than do the bearings. This however, is not the general practice, and most outfits compromise the situation by using the same oil on the gears as on the bearings.

Summary and Conclusions

With reduction gears the same specifications apply as to refinement, operation, flash point and acidity, as outlined for bearings in the July issue of the Review, i.e., it should be a highly refined mineral oil without the admixture of fatty oils, and should have a low evaporation loss and practically no acidity. The question of viscosity and emulsion, however, should receive further consideration in the case of reduction geared units other than given for turbines without reduction gears. Most manufacturers of reduction gears require that the viscosity of the oil used on gears shall be 300" Saybolt at 100° F. or higher and in fact some gear manufacturers require that the viscosity shall be at least 500" Saybolt at 100° F. As stated in the preceding article, the viscosity of the oil used in bearings should be about 180" Saybolt at 100° F., though in some cases a lower viscosity can be used if all conditions are ideal. This lower viscosity desired for the best operation of bearings over that required for gears can easily be accomplished by allowing or causing 300" or 500" oil to operate at a higher temperature in bearings than would be required if 180" oil were used. This might be considered a drawback if a great difference in temperature were required, but such is not the case. Satisfactory turbine oils are made that have a large temperature coefficient, i.e., that lower their viscosity rapidly with rising temperature. This fact allows a 300" or 500" oil to be used on bearings and yet necessitates only a rise of 10° to 25° F. in the bearing temperature over that which would normally exist if 180" oil were used. This use of higher temperatures in bearings with high viscosity oils will not cause excessive evaporation losses or decomposition, for if properly refined, high viscosity oils do not evaporate or decompose as rapidly as low viscosity oils at the same temperature. As oil pressures, speeds, tooth pressures and general systems vary to such a large extent it is impractical to make a general recommendation as to what temperature is most suitable for bearings when lubricated from the same lubricating system as gears and each system must be considered separately.

In marine outfits particular attention should be given to the separation of oil from salt water as well as fresh water, and as high viscosity oils separate more slowly from water than low viscosity oils, a slightly higher temperature should be maintained in the settling tank in order to obtain the best results.

Electricity in the Lumber Industry

ELECTRICAL INSTALLATION AT THE CARLISLE-PENNELL LUMBER COMPANY, ONALASKA, WASH.

By J. M. Dodds

Seattle Office, General Electric Company

In our issue of July we published an article by E. F. Whitney on "Electrical Applications in the Logging Industry of the Northwest," which, together with our present contribution should be of value to all those interested in the lumber industry, and especially to those contemplating electrification with the hopes of reducing operating and maintenance costs. It seems that the time has arrived when the logging industry must adopt electrification if they are to reduce these costs to within a reasonable figure. The author follows a log through the mill step by step and tells of the kind of machinery used for some of the more important applications.—Editor.

The story of the development of the lumber industry in the great Northwest, of the subjection of the vast forests to the needs of mankind, and of the adaption of electricity, man's most potent slave, to that industry, is far too extensive to cover through any medium but a book. The competition, incident to any predominating industry, together with the unusual commercial and manufacturing situation that has prevailed during recent times, has required that manufacturers seek and adopt the most advanced and effective equipment available. This has brought about many radical changes in operating practice. The advent of the eight-hour day has augmented this demand.

Electrical equipment has played a large part in speeding up production and cutting down maintenance and operating costs. The analytical study given to the necessary power applications has developed a number of special motor drive schemes not previously used which have all tended toward elimination of waste motion and power and the consequent saving of repair and up-keep costs.

Never before has the saw mill industry seen so many and such large changes, from steam to electric drive, as have been made during 1920. Few new mills were constructed during this period, so that the large volume of mill electrification is the more striking. It has meant the change over from steam to electric drive of established leading mills, some of which have been operated by steam power for over fifteen years, while others were new steam-driven mills scarcely three years ago. Today this three-year-old steam-drive equipment has been considered too costly to operate and has been removed to make way for complete electric drive.

The purpose of the following description of typical milling operations and the accompanying data is twofold: To give the electrical man a clear view of modern saw mill requirements, and to give the lumberman a brief resume of the electrical possibilities which the leading saw mills are turning to their advantage.

The Onalaska Mill of the Carlisle-Pennell Lumber Company, shown in Fig. 1, is a good example of one of the large modern saw mills which has been remodeled. Some of the steps preceding the saw mill operation, which come under the field of logging work, are:

- Falling the standing tree;
- Trimming the fallen tree;
- "Bucking," i.e., sawing the tree into desired log lengths, usually 32 to 48 feet;
- "Yarding," or gathering the logs from their fallen position to the track side for loading on the cars;
- Loading upon the special log cars, and hauling to mill site or tide water, and
- Dumping into the log pond, or into tide water, in the case of water transportation.

These operations comprise a field distinct from the saw mill, and electric motors have been successfully applied in the woods.*

In the log pond the logs are selected as needed, sawed into suitable lengths with a specially arranged cross-cut saw, and floated to the log haul. Here they are hooked by the "dogs" on the log haul chain and pulled slowly, endwise, up and over the arched incline to the log deck of the mill. Enroute they are given a generous washing by many jets of water under pressure which removes sand and rocks embedded in the soft bark. See Fig. 2. Both the log haul and wash are motor-operated, the former driven through a friction clutch; the latter service is performed by a three-stage centrifugal pump.

The mill plan is shown in Fig. 5. Arrows indicate the progress of the lumber through

* See Review, July, 1921, p. 631, "Electric Applications in the Logging Industry of the Northwest."

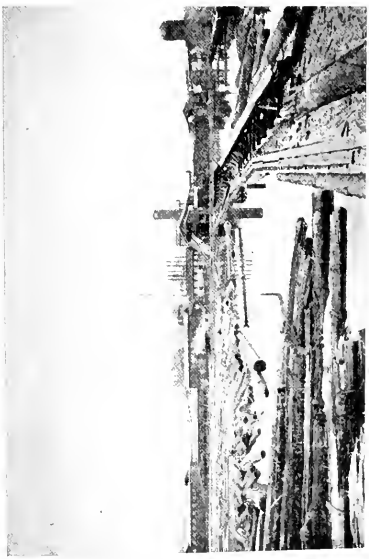


Fig. 1. A General View of the Carlisle Pennell Lumber Company's Plant at Onalaska, Wash., showing to the extreme left the Planing Mill, then in the order named, the Fuel Storage House, Boiler Plant, Main Saw Mill, Shingle Mill and Refuse Burner

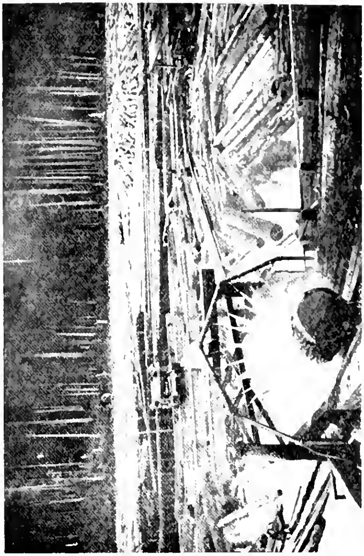


Fig. 2. Log Pond, Log Haul, and Washing Device

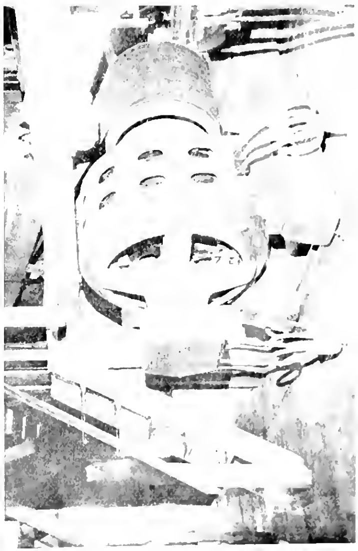


Fig. 3. 300 h.p., 600-r.p.m. Induction Motor Driving 11-in. Band Head Saw

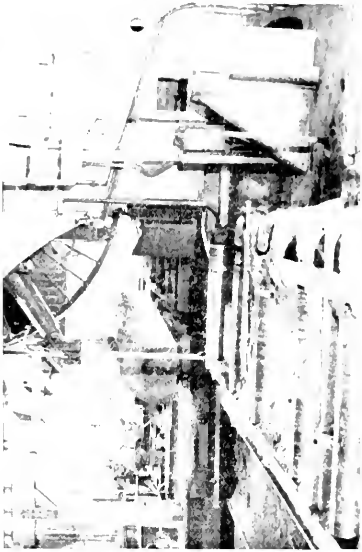


Fig. 4. View of Head Saw from the First Section of Live Rolls

the mill until it finally reaches the main sorting tables or the timber docks, which are the outlets from the mill for all completely manufactured rough lumber.

Arriving at the log deck the logs are scaled for quantity of lumber and rolled off against log deck stops, awaiting their turn to pass through the head saw and join their comrades on their way through the mill.

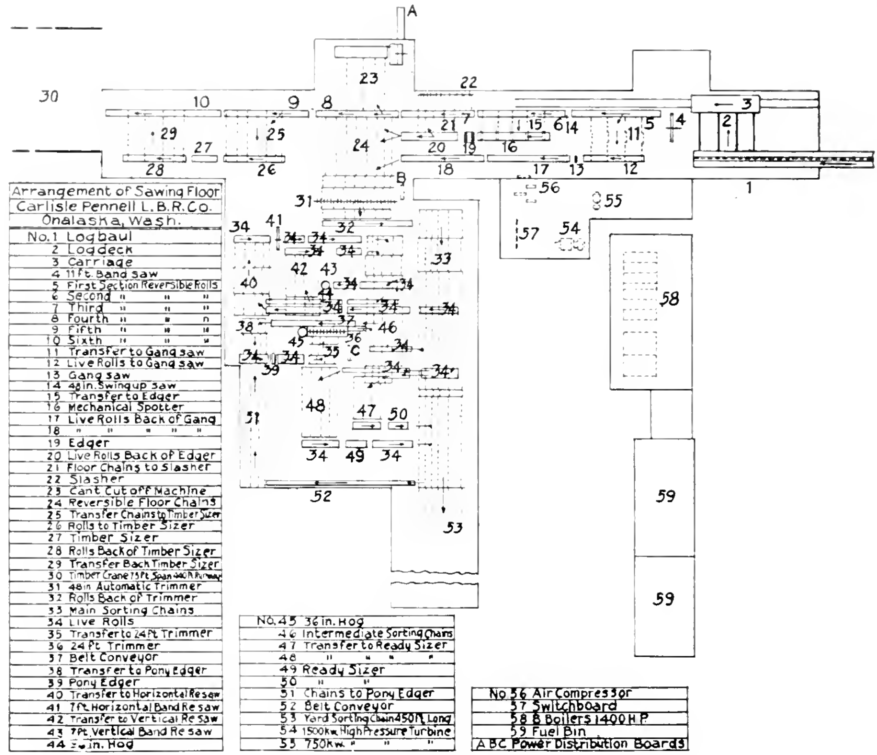


Fig. 5. Plan of the Sawing Floor

The Head Rig

The eleven-foot band head saw is driven by a 300-h.p., 3-bearing motor with enclosed dust-proof collector rings, as shown in Fig. 3. The speed of this saw is 10,500 ft. per min. During the sawing process the logs are carried on the log carriage. The rate of feeding the logs to the saw varies from 150 to 400 ft. per min., depending upon the size of the cut. The saw kerf is about one quarter of an inch, so that this thickness of wood is removed as sawdust. During the latter part of the return movement of the carriage the log is moved up into place for another cut by the Set Works, which is belted to a 10-h.p. motor mounted on the carriage. The latter is supplied with power from a three-wire trolley suspended over the carriage track. This makes a very durable and economical combination for the head works. Reliability is paramount, because all the timber passes through the head saw, and its disability shuts down the entire mill. A good general idea of the arrangement of these units may be seen in Fig. 4.

It is not unusual for the power input to the head saw motor to reach double the rated value. Its load factor is low. The following data, including power readings, are representative of several cuts in fir.

Length of cut, ft.	40	32	32	32	28	28
Depth of cut, in.	36	24	24	28	14	16
Time, sec......	15	12	10	13	9.5	7.5
Kw., input....	364	274	336	279	288	384
Feed, ft. per min	160	178	192	147	176	225
Volume wood cut, cu. ft. per min....	10.0	6.66	8.0	7.2	4.30	6.20

It should be of interest to refer to the accompanying curve, Fig. 6, showing the power input to head saw or edger plotted against the rate of removing wood.

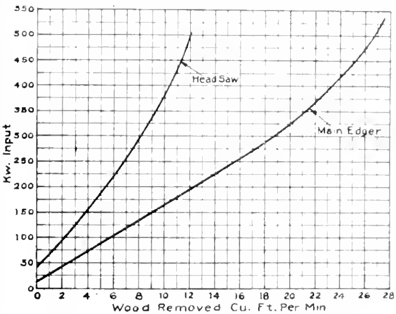


Fig. 6. Curves Showing Power Input to Head Saw and Main Edger

Live Rolls

Live rolls, viz., power-driven, are used throughout the mill. They offer one of the most useful applications of the electric motor. A very successful drive, as used in this mill, consists of a 10-h.p. motor mounted on a back-gear base. The sprocket on the slow-speed shaft of the back-gear is chain-connected to the live roll section drive shaft. This gives a semi-rigid direct drive which eliminates a great deal of transmission equipment, the upkeep of which is usually a considerable item. The motor and back gear are best mounted just beneath the mill floor. A master starting switch is mounted on the main floor convenient to the operator for starting and reversing the rolls. This switch controls contactors in the control panel box mounted below. The motor is of special design for high torque continuous duty and is started without a compensator. This makes a very desirable combination for this application.

The cant, leaving the head saw, falls upon the first section of live rolls and is conveyed, at a speed of approximately 420 ft. per min. on its journey through the mill. The speeds of the second, third, fourth, fifth and sixth section of rolls decrease in steps.

The Main Edger

The main edger, shown in Fig. 7, cuts the cants from the head saw into the desired widths. From one to six cuts may be made in the cant at the same time. The saw arbor is directly connected to a 300-h.p., 1200-r.p.m. induction motor. In addition to the main drive, the feed mechanism is driven by a multi-speed induction motor rated 12 h.p., which gives a cant speed of from 133 to 400 ft. per min. The ease with which the electric power drives this machine gives no indication of the unusual loads and stresses. The power input to the main drive reaches 600 kw. at times, but there are no belts to slip and burn or noticeable lag in speed. The illustrations give an idea of the economy of space of the electric drive.

The Trimmer

Having been cut to width and thickness suitable for resawing to the required lumber size, the cant is now ready to be trimmed to the necessary lengths. This is done by passing side-wise through the trimmer, where one or more of 25 circular saws are dropped down into the cutting position. The lift of these saws is air-controlled. These trimmer saws are driven by a 75-h.p. induction motor direct connected to the saw arbor to which the saws are belted. See Fig. 8.

Resaw Room

The lumber now goes to the resaw room where it passes back and forth, through one or the other of the various machines, to be ripped, edged, trimmed and graded into the final board ready for the planer, dry kiln or lumber pile.

The diagram, Fig. 5, shows the mill floor plan, with arrows showing the direction of the lumber as it passes through the mill. Here it will be seen that it leaves the main trimmer and falls on the first section of the main sorting chains, which are, in common with the others, motor-driven. The cants are removed from these chains at the proper time by motor-driven rolls, which are lifted

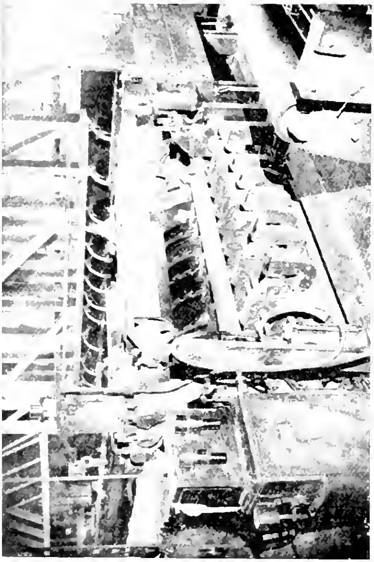


Fig. 7. View of 12 by 72 in. Edger. Starting Compensator at Left, Controller for Feed Rolls at Right

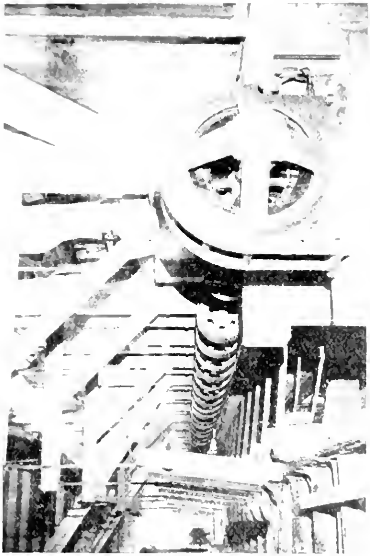


Fig. 8. 75-h.p., 600-r.p.m. Induction Motor Driving a 50-ft. Trimmer

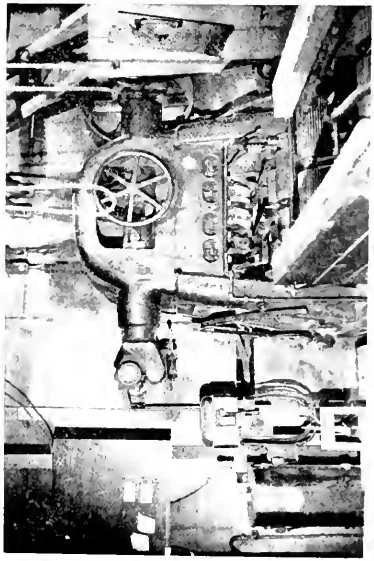


Fig. 9. Six-foot Horizontal Band Resaw and Control

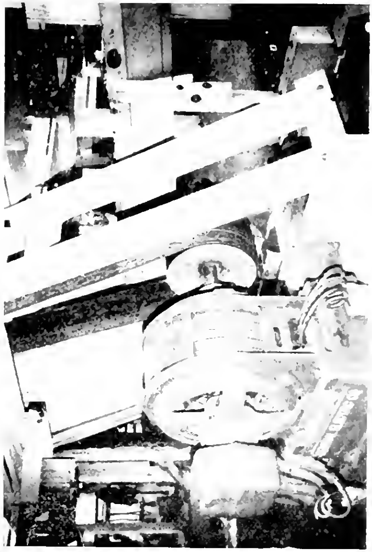


Fig. 10. 150-h.p., 720-r.p.m. Induction Motor Driving 6-ft. Horizontal Band Resaw

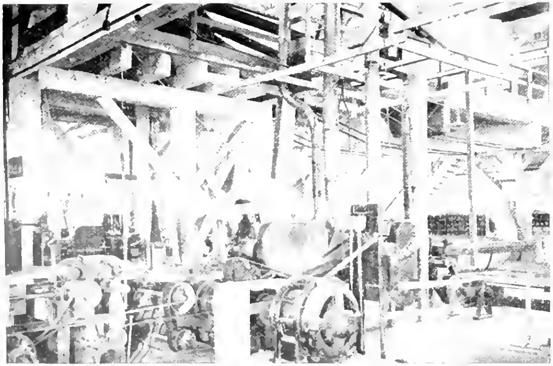


Fig. 11. 75-h.p., 1200 r.p.m. Induction Motor, Direct-connected to a 6 by 15-inch High-speed Matcher

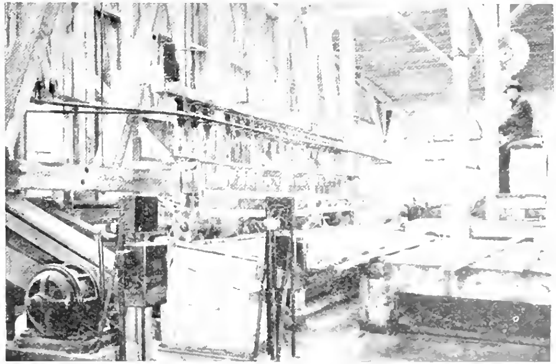


Fig. 12. 20-h.p., 1200-r.p.m. Induction Motor Driving a 20-saw Pony Trimmer

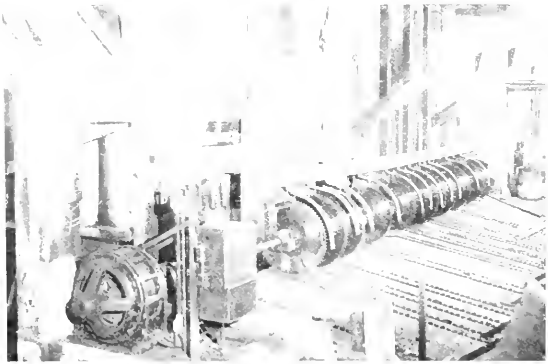


Fig. 13. 50-h.p., 900-r.p.m. Induction Motor Driving Saw Slasher

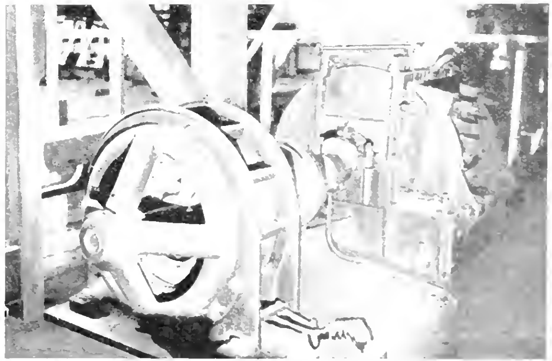


Fig. 14. 40-h.p., 900-r.p.m. Induction Motor Direct-connected to [illegible] Taking Refuse from the Remanufacturing Plant Machines

under the cant, and conveyed to one or the other of the remanufacturing machines. See Figs. 9 and 10. Thence by chains or rolls the boards are taken either to the pony edger, pony trimmer, or again to the resaw, until they are finally taken to the intermediate sorting chains and thence to the ready sizers or the main sorting chains. The motor-driven ready sizers plane the green lumber on one side and an edge.

Dry Kilns, Planing Mill

Leaving the resaw room on the main sorting chains the boards finally arrive in the sorting shed, where they are piled on trucks, some for the lumber yard, and some for the dry kilns. The trucks are pulled to their destination by electric driven tractors. Those for the kiln are taken to the stacker shed, where the boards are stacked on edge on the kiln cars by an electric-driven stacker.

After drying, the cars leave the kiln and are unstacked by a motor-driven machine and are sorted and graded for the planing mill. The bundles are then picked up by a crane and conveyed to the proper planing machines, which are, of course, also motor-driven, as shown in Fig. 11. Here again the boards pass through a motor-driven trimmer, illustrated in Fig. 12, are graded, and finally packed for shipment.

Conveyors, Fuel Hogs, Slashers

Throughout the mill, refuse material is handled by chain or belt conveyors, each driven by an individual motor. Edgings and useless slabs are passed side-wise on chains past a battery of saws direct-connected to one motor, the slasher, seen in Fig. 13, and are cut into 4-ft. lengths for the burner conveyor, which takes them to the large refuse burner. From this main refuse conveyor, before it reaches the burner, is taken such of the slabs as are desired for stove or cord wood, or for further manufacture into lath, stakes or other small special articles. At convenient places along the refuse conveyors, hogs, as shown in Fig. 14, are installed, direct-connected to motors. These receive refuse from the trimmers and edgers and cut it into coarse wood chips, known as "hogged fuel." This is the source of fuel for the mill's boiler plant.

The Shingle Mill

The cedar which is found growing with the fir, and is logged with it, is segregated at the pond and is floated to the shingle mill, which is also electric-driven throughout. The logs are hauled up an incline similar to that of the saw mill and are cut into blocks of shingle length by a large swinging circular saw belt-connected to a motor. The shingle bolts are placed in one of the six motor-driven automatic shingle machines. A motor-driven circular saw is arranged at each machine for trimming the shingles, which are then dropped into bins ready for the packers and dry kilns.

The Engine Room

The power house, containing two turbine generators, one of 1500-kw. capacity, and one of 750-kw. capacity, is the source of electric power for the entire mill and town. The accompanying illustrations, Figs. 15, 16 and 17, show the engine room arrangements. Fire protection of the very highest order prevails in this mill.

On account of the high steam economy of the turbines and power efficiency of the electrical machinery, the 1400 boiler horse power installed is adequate for the mill, dry kilns and other steam uses, and leaves spare capacity not required for continuous use.

In the engine room are motor and steam-driven air compressors, as illustrated in Fig. 18, for operating various lift cylinders about the mill. The switchboard dispatches power to the head saw, edger, shingle mill, planing mill and three different power distributing panels located at centers of distribution. See Fig. 17.

RECAPITULATION

It is of interest to study for a moment the saw mill operator's viewpoint on electric drive. With the line shaft drive scheme he is accustomed to push his machine to a capacity that will not quite slip the belts, or to a point where the speed will "lag" if pushed further. With motor drive there is no appreciable drop in speed until the load reaches 200 to 300 per cent of normal, and when the overload protection operates he feels that something is wrong with the equipment. The designer has two limits between which to choose a medium, one of putting sufficient capacity into the motor to drive the machine under any condition of load, even to destruction of the sawing equipment, and the other of selecting a motor capable of doing a limited and predetermined amount of work. In the first case the safety of the machine or saw is risked, and in the second that of the motor.

The duty of nearly all saw mill machines is an extremely variable quantity. Each is

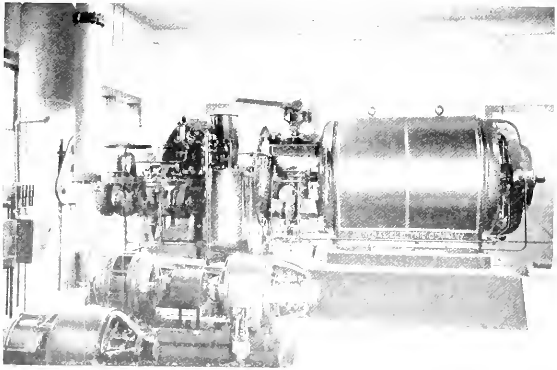


Fig. 15. 1500 kw. Condensing Curtis Turbine Generator Operating Main Saw Mill and Remanufacturing Plant

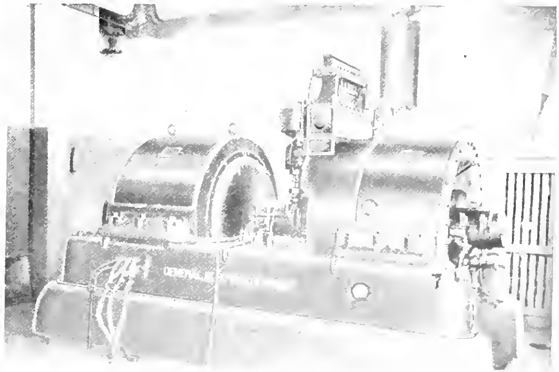
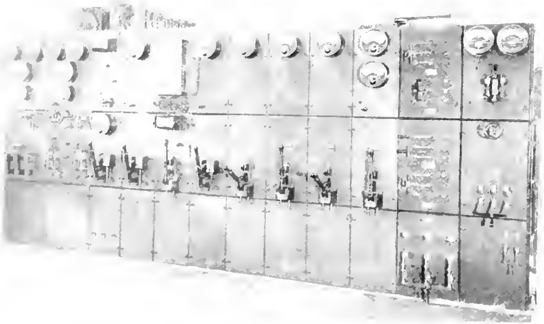


Fig. 16. 750 kw. Condensing Curtis Turbine Generator



Fi[illegible]. Main Distributing Switchboard

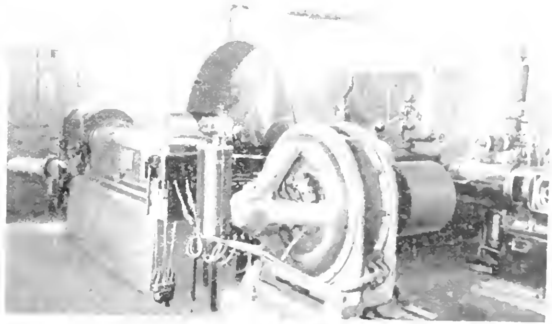


Fig. 18. 100 h.p., 900 r.p.m. Induction Motor Driving Air Compressor

called upon to perform diversified tasks, for each must handle the material as it comes through the mill without a slow-up in production. The general policy is therefore to choose motor equipment of such capacity that the maximum duty will cause it no distress. This practice means that certain machines operate at a low load factor, but this disadvantage is more than compensated for by maintained production during periods of maximum duty.

The curves in Fig. 6 show the variation of power input with the rate of sawing, for the edger and head saw. These are plotted from data taken during tests on the respective machines. These curves represent a mean of many measurements. The individual tests follow the curves in a general way, scattering on one side or the other, in some cases a relatively long distance from the curve.

The power input to the head saw increases much more rapidly than that to the edger, mainly because the increase in cubic feet cut with the edger is obtained by using additional saws, while with the head saw it is obtained by loading the teeth more, and perhaps filling up the saw. With a wide cut the saw teeth are in the cut a greater length of time. The saw teeth, however, have a fixed dust-carrying capacity and this must not be exceeded, so the rate of feed must be less for a wide cut than for a narrow one. In these curves the rate of cutting is expressed in cubic feet of wood removed per minute, and not of sawdust.

The sawyers who have formerly believed that electric power was all right for a steady load but unsuited for variable duty, are always agreeably surprised to see the sturdy motor "hang on" to the load as the saws bite into a heavy cant and to see that the speed does not drop as it "used to do" when steam engine and belt drive were used. From then on they are good friends of the electric drive.

Power requirements of saw mills vary according to the particular product produced. Some specialize quite largely in timbers and heavy lumber, sacrificing some quality for quantity of production, while others carry the manufacturing process further and attempt to rescue the last foot of "clear."

The output of former type mill will be larger than that of the latter type and also the energy requirements for each unit of output will be less in the former type than in the latter. The mill under consideration is an inland mill, so that all shipments are by rail. Its power requirements are as follows:

Average power for saw mill is 1130 kw., or 41.8 watt-hours from log to sorting table per board foot of timber cut. This does not include shingle mill, planing mill or gang saw. To include the gang saw this figure should be raised to approximately 48 watt-hours per board foot. For the planing mill with a capacity of 12,500 board feet per hour and average load of 317 kw., we find a power input of 25.4 watt-hours per board foot. The shingle mill, with a capacity of 25,000 shingles per hour, and average load of 183 kw., gives 0.0073 kw. per shingle per hour, or the work per good shingle is 7.3 watt-hours.

Following are the ratios of average to connected load:

For the mill, exclusive of shingle and planing mills, we find an average load of 1130 kw. and connected load of 1878 kw., giving a ratio of 60 per cent. The shingle mill gives a ratio of 88.5 per cent, with average load of 183 kw. and connected load of 207 kw., and the planing mill a ratio of 67.5 per cent, having a connected load of 470 kw. and an average of 317 kw.

The following is a table of motors installed in this plant:

NUMBER OF MOTORS INSTALLED

Horse Power of Motor	Saw Mill	Shingle Mill	Planing Mill	Total	Total Horse Power
2	1	0	2	3	6
3	9	6	0	15	45
5	6	1	5	12	60
7½	13	0	7	20	150
10	25	3	0	28	280
15	4	1	2	7	105
20	5	6	3	14	280
25	6	0	1	7	175
30	3	0	0	3	90
35	1	1	2	4	140
40	1	0	0	1	40
50	5	1	3	9	450
75	6	0	0	6	450
100	2	0	0	2	200
150	1	0	0	1	150
200	0	0	1	1	200
300	2	0	0	2	600
Totals	90	19	26	135	3421

Automatic, Polyphase, Brush-shifting Motor-driven Draft Fan Installation at Springdale Station West Penn Power Company

By R. A. Jones

Power and Mining Engineering Department, General Electric Company

The development of a successful automatically regulated motor operated draft fan will interest operators of large steam power plants. The requirements of the service involve a wide range in speed, and as the power demands are considerable, high efficiency and power factor are important considerations and a motor having all three characteristics should be employed. The polyphase brush shifting commutator motor was selected for the draft fan installation described in this article, and although the control is much more complicated than usual for this type of motor, including overload and under-voltage protection, push button stations for starting and stopping, automatic speed control from pressure regulator, speed control from two push button stations, and a change in the stator windings from delta to Y, the equipment has functioned perfectly and in addition to maintaining steady boiler pressure it has effected an appreciable saving in cost of operation.—Editor

The forced-draft fan equipment recently put into operation at the Springdale Station* of the West Penn Power Company is of special interest at this time, as it includes a comparatively new type of polyphase, alternating-current, varying-speed, brush-shifting motor that eliminates the objectionable poor efficiency and limited number of speed points inherent with slip-ring induction motors and provides a satisfactory and easily controlled alternating-current fan drive which can be advantageously applied in large generating stations. Motors of this type were developed by the General Electric Company approximately eight years ago and their success has been thoroughly demonstrated for textile mill, pump, mine fan, and general ventilating fan service, a considerable number of units having been in operation for seven or eight years.

The equipment described in this article is, however, the first application of this type of motor with full automatic control to power station auxiliaries. In general, the duty imposed does not differ materially from that of other fan applications, except for the continuously varying speed operation with automatic control.

The actual duty of the equipment and its relation to the operation of the entire station may be briefly explained as follows:

The total station capacity of 50,000 kv-a. is supplied by two 25,000-kv-a., 3-phase, 60-cycle, 12,000-volt turbine-generator units, each of which feeds into a separate bank of transformers that step up the transmission voltage to 66,000. The steam for the turbine units is supplied by four boilers with automatically controlled induced and forced-draft fans.

There are two stoker motors per boiler, each automatically controlled from pressure regulators or manually controlled from push-button stations.

The induced-draft fan equipment for each boiler consists of two centrifugal fans coupled together and driven from one end through a flexible coupling by a 175-h.p., 514-r.p.m., 2200-volt, 3-phase, 60-cycle slip-ring induction motor and from the other end through a magnetic clutch by a 400-h.p., 720-r.p.m. slip-ring motor. Secondary resistance is provided to give a speed range from full-load speed to 450 r.p.m. with the 400-h.p. motor, and from the latter speed to 255 r.p.m. with the 175-h.p. motor. The control, like that of the stoker motors, is arranged for push-button or pressure regulator operation and in both cases the regulators are to be operated by steam pressure.

By dividing the induced-draft fans into two units, it was possible to use smaller and higher speed equipment and materially reduce the cost of both the motors and fans in addition to saving considerable floor space. This arrangement suggested the desirability of using two motors, one on each end, so as to provide protection against complete shutdown. If one fan should fail, the coupling between the two could be disconnected and the other unit kept in operation. In case of a breakdown of the 175-h.p. motor, it would be necessary to open the flexible coupling and drive both fans with the 400-h.p. motor. Ordinarily both fans will be driven by the 175-h.p. motor as this has sufficient capacity to operate the boilers at 300 to 350 per cent rating.

The use of two motors in this way decreased the speed range required of each, and also made possible the selection of motors having speeds such that the normal operating point was near the full-load speed of the smaller motor. This arrangement greatly increased the operating efficiency, since it eliminated extensive reduced speed operation. In addi-

* Springdale, Pa.

tice the limited number of speed points with slip-ring motor control was not as objectionable to induced-draft operation as it was to forced-draft, and therefore it was decided not to use a brush-shifting motor for the induced-fan equipment.

The forced-draft equipment for each boiler consists of one centrifugal fan having a capacity of 94,000 cu. ft. per minute at 5.90 inches water gauge pressure, 65 deg. F., 770 r.p.m. and driven by a 10-pole, 150-h.p., 720-r.p.m., 2200-volt, 3-phase, 60-cycle, alternating-current, variable-speed, brush-shifting motor with push button and pressure regulator control. The pressure regulator is actuated by the variations in the draft over the fire.

As a protective feature, all the fan control is so interlocked that the forced-draft fans cannot start or continue to run unless the induced-draft fan is in operation. This is to prevent the possibility of an accumulation of combustible gases over the top of the fire, which condition might result in an explosion.

An idea of the mechanical arrangement of the forced-draft fan equipment can be obtained from Fig. 1. All the units are located below the boiler room floor and have their suction inlets arranged to utilize the warm air discharged from the turbine-generators so as to return the generator heat losses to the boilers. The discharge ends of each row of fans empty into a common flume, extending the full length of each row of boilers. With this arrangement, failure of any fan unit will not shut down its corresponding boiler since dampers, which normally isolate each boiler, may be opened and one fan be forced to supply two units.

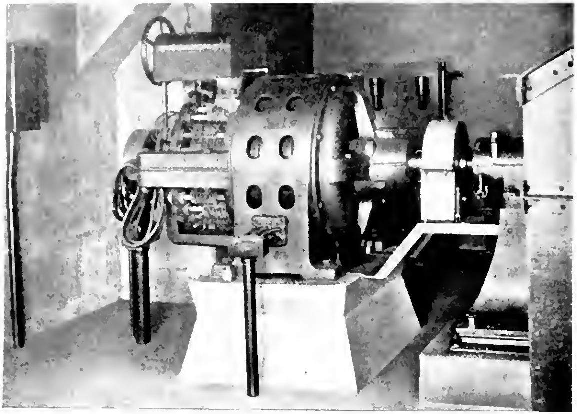


Fig. 1. 150-h.p., 720-r.p.m., 2200-volt, Varying-speed Brush Shifting Motor with Automatic Brush Shifting Mechanism Direct-connected to Forced Draft Fan. The panel mounts the pilot motor, contactors and brush shifting motor overload relays. One push button station and control circuit transfer switch is mounted on the wall

The power supply for all of the fan equipments is obtained from the station auxiliary bus which is arranged to receive power from the house turbine or from either of two banks of main power transformers.

The motor characteristics and control features of the forced-draft fan equipment are fairly complicated and warrant the following detailed description:

As previously stated, the motors are alternating-current, varying-speed, brush-shifting machines, and are rated 150 h.p. at the synchronous speed of 720 r.p.m. However, the motors are also capable of operating above synchronous speed and have sufficient capacity to drive the fans at 865 r.p.m. intermittently and 825 r.p.m. continuously. The lowest operating speed required is 355 r.p.m., resulting in a total speed range of 2.45 to 1. The maximum limit of 865 r.p.m. corresponds to the full-load speed of 900-r.p.m. slip-ring induction motors, and therefore permits the direct comparison given later.

A general idea of the theory of operation of the motor may be had by comparing it with a direct-current, series-wound motor. Referring to Fig. 2, we have a stator and rotor built up of punchings and provided with coils, connected in series, through which current flows, derived from a direct-current source. The magnetomotive forces, due to the stator and rotor coils, directly oppose each other. If we assume that the coil on the rotor has more turns than the coil on the stator, we may picture by vectors, as shown, the direction and value of the resultant magnetomotive force, *M.M.F.F.*, which excites the resultant field flux *F*. The direction of this field flux is such that the pull exerted on each side of the rotor coil, due to repulsion between the current in the coil and the magnetic field, is along the same line and directly opposite as illustrated by the arrows a and b. This does not give rise to any torque.

In Fig. 3, we have the rotor in a different position, turned through angle A. The resultant flux F, shown by the arrow, has changed its direction and the pull a and b on both sides of the rotor coil has the components c and d which exert a torque that tends to turn the rotor clockwise.

It is evident that the useful flux for producing torque lies along the plane of the rotor coil. Therefore, the resultant flux F may be resolved into components in the same way as a and b. The component of F which is useful in producing torque, expressed in terms of the stator flux, as shown by Fig. 3, equals the stator flux $M.M.F.S.$ times the sine A. Therefore, when angle A equals zero the torque producing flux is also zero, as shown above. When A equals 90 deg. the torque is maximum since the sine of 90 deg. is unity, and at 180 deg. the torque is again zero, which shows that shifting the rotor axis varies the torque.

Now, if we provide the motor with a commutator and brushes and allow it to rotate, holding the brushes in position, thereby fixing the rotor axis, the same theory still applies and we have a direct-current series motor. If alternating current is applied, there will still be torque in the same direction because both the field flux and rotor currents are reversed simultaneously. We can also substitute a smooth core stator for the salient poles used in most direct-current machines without affecting our reasoning.

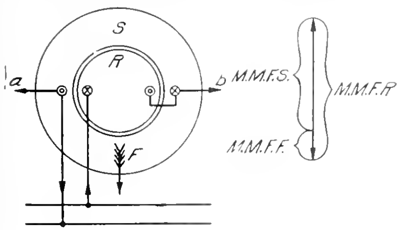


Fig. 2. Elementary Diagram with Rotor Axis in Live Neutral Position

Again referring to Fig. 3, it is also evident that a change in the rotor axis, resulting from shifting the brushes, will cause a change in speed. When angle A equals zero there is no torque and therefore no speed. If A is increased a small amount, the rotor and stator flux nearly buck each other; the resultant flux F is small and the motor will tend to rotate rapidly in order to generate a counter electromotive force that will balance the applied voltage. As A increases, the resultant flux F continues to enlarge and the speed necessary to generate the counter

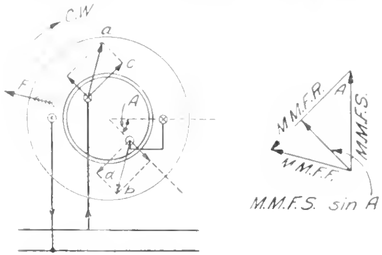


Fig. 3 Elementary Diagram with Rotor Axis Shifted Through Angle A

electromotive force decreases, and so on until, when A equals 180 deg., the torque and speed are again zero.

It is to be noted that, when A equals zero and the stator and rotor flux oppose each other, the motor has a low impedance. If full

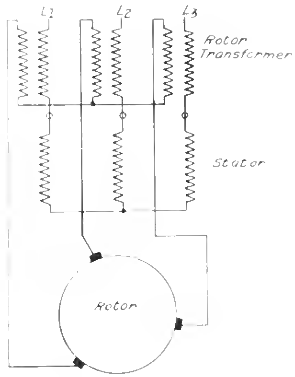


Fig. 4 Diagram of Connections for 3 phase Motor with 3 phase Rotor

voltage were applied, a large current would flow. Also, when the axis of the rotor is shifted in either direction a torque is produced in the same direction. This is, therefore, called the live neutral. When A equals 180 deg. the stator and rotor flux combine, resulting in a high impedance, and any shifting of the rotor axis produces a torque in the direction opposite to the shift. This is called the dead neutral.

So far we have considered a single-phase, alternating-current, series motor and have seen why shifting the rotor axis changes the speed and torque. The polyphase motor is merely a combination of single-phase machines

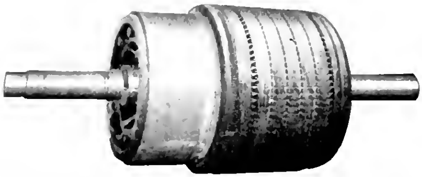


Fig. 5. Armature of 150-h.p., 720-r.p.m., 2200-volt Varying-speed Brush-shifting Motor

and operates in the same way except for additional advantages which inherently improve the commutation and power-factor.

In actual construction the motor consists of a stationary member or stator, a rotating member or rotor, and a transformer connecting the rotor in series with the stator, as illustrated by the elementary diagram of connections in Fig. 4.

The stator has a distributed winding and is similar to the ordinary induction motor. Frequently the stator of an induction motor of the same number of poles, horse power, voltage, and frequency can be used without change.

The rotor, Fig. 5, is in appearance and design essentially like that of a direct-current motor or generator, except that for the brush-shifting motor the armature voltage is considerably lower, being approximately 80 to 90 volts.

The rotor transformer is simply a series transformer with the primary in series with the stator of the motor and the secondary connected to the rotor through the brushes and commutator. This transformer not only supplies a lower commutator voltage, but also, by its ability to become saturated, limits the no-load speed of the motor to a safe value. This limit is approximately 150 per cent speed.

A general understanding of the action of the transformer saturation in limiting the maximum speed can be obtained by thinking of the motor rotor as the rotor of a slip ring induction motor. As the speed varies from synchronism, the voltage across the rings increases. This increases the counter electromotive force opposing the secondary voltage of the rotor transformer. Therefore, unless the transformer secondary voltage increases, the current and torque reduce with a corresponding decrease in speed. Since the maximum transformer secondary voltage is limited by the transformer saturation, the speed is therefore limited.

The control actually required for operating this type of motor is extremely simple, consisting merely of a switch for connecting the motor stator to the line and some mechanical means of shifting the brushes, the starting current and starting torque being determined by the position of the brushes.

For the Springdale installation the control is more complicated since it provides overload and under-voltage protection with push-button start and stop in addition to automatic speed control from a pressure regulator, and from two push-button stations. Another feature that further complicates the control is the changing of the motor stator connections from delta to Y, and automatically shifting the brushes to compensate for the accompanying change in speed.

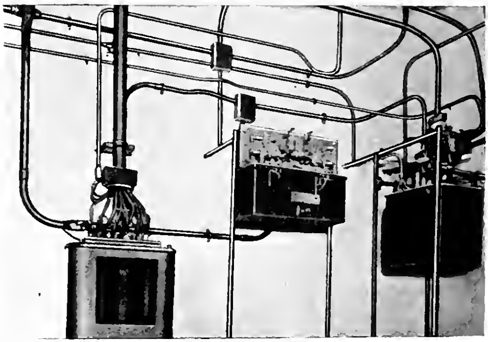


Fig. 6. Oil Immersed Line and Y-delta Contactors and Rotor Transformer for 150-h.p., 720-r.p.m., 2200-volt Brush-shifting Motor

Since the torque required to drive a fan decreases rapidly with the speed, the motor is not fully loaded at reduced speeds and can, therefore, be operated with a lower line voltage. Changing the motor connections from delta to Y is equivalent to reducing the voltage and results in improving both the efficiency and power-factor at the low speeds.

This change in voltage naturally changes the speed for the same brush setting.

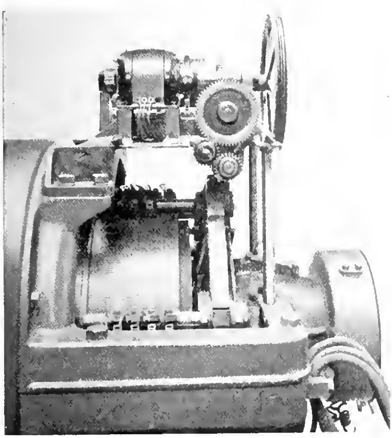
The actual control equipment necessary to provide these features consists of the following:

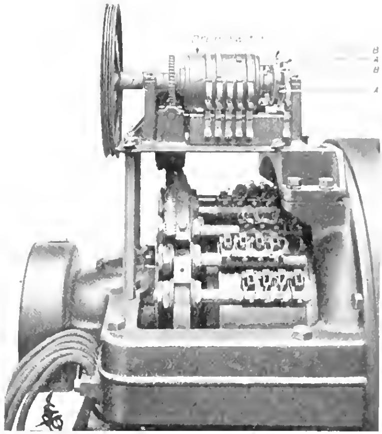
Primary control (Fig. 6) consisting of oil immersed line and delta-Y contactor panels, with necessary interlocks. The rotor transformer is also shown at the left.

Secondary control (Fig. 1). More detailed views (Figs. 7, 8, and 9) show the brush-shifting pilot motor, gear train, and drum control switches, arranged for pressure regulator control through the rope wheel or for push-button control. The panel shown at the rear of Fig. 1 mounts the brush-shifting motor overload relays and the forward and reverse contactors for the pilot motor. One of the push-button stations with the necessary control circuit transfer switch is shown on the wall at the extreme left.

Referring again to Figs. 7, 8, and 9, it will be noted that the pilot motor is geared to the brush rack and to the large drum switch as shown by Fig. 8. This drum is on a hollow shaft and rotates independently of the rope wheel. The control circuit for the pilot motor is carried by two fingers, mounted on the end of the larger drum, which travel over contact segments on the two small cylinders A, Fig. 8. The other five contact segments and fingers provide the necessary limit switches, delta-Y contactor control, and automatic shifting of the brushes to compensate for the change in speed incident to a delta-Y change in the motor windings.

With both control circuit transfer switches thrown to the "up" position, the speed control is entirely automatic. Any variation in the draft suction over the fire, caused by the operation of the induced-draft fans or change in thickness of the fire, will cause the pressure regulator to turn the rope wheel and adjust the brush-shifting motor speed so as to compensate for this change in draft. The control arrangement with the drum switches, as described, provides a "follow-up" system which causes the speed of the motor to follow the movement of the pressure regulator. To illustrate, assume the motor to be running at any speed. A change in draft conditions causes the regulator to adjust the rope wheel position and one of the





Figs. 7 and 8. Two Views of Pilot Motor Gear Train, Rope Wheel, and Drum Control Switches for Automatically Controlling a 150-h.p., 2200-volt Brush-shifting Motor from Push Buttons or Pressure Regulator. Cover Removed.

segments on the small cylinders A, Fig. 8, comes in contact with the finger B carried by the large drum. This starts the pilot motor, which continues to run, shifting the brushes on the commutator and revolving the large drum switch until the fingers no longer make

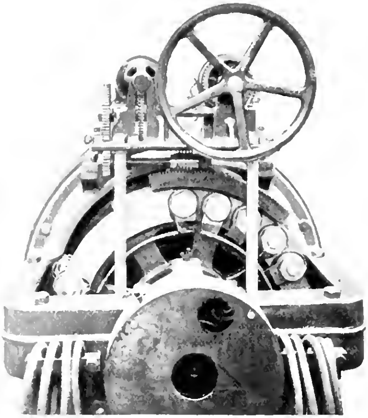


Fig. 9 Another View of Control Equipment for 150-h.p., Brush-shifting Motor

motor from the two push-button stations at the same time, no harm will result. The operation of the push-button control is similar to that of the full automatic, except that it is independent of the rope sheave and does not automatically compensate the speed for the delta-Y change. As long as a fast or slow button is held in, the motor continues to change in speed between the limits predetermined by the limit switches.

For service of this kind, where infinite speed adjustment and high efficiency and power-factor are desirable, the brush-shifting motor is decidedly advantageous. The curves in Fig. 11 give actual test values, comparing the efficiency and power-factor of the 150-h.p., 720-r.p.m. brush-shifting motor and a 900-r.p.m. slip-ring motor of the same size under actual fan load. The curves include speeds up to 825 r.p.m., which is the normal operating range over which the performance of the two motors should be compared. The break in the curves is due to the delta-Y change.

The benefit of this higher efficiency and power-factor is more clearly shown by the curves in Fig. 12, which give the comparative kilowatt and kilovolt-ampere input for the brush-shifting and the slip-ring motors when driving the fan at different speeds. It is evident from these curves that the actual

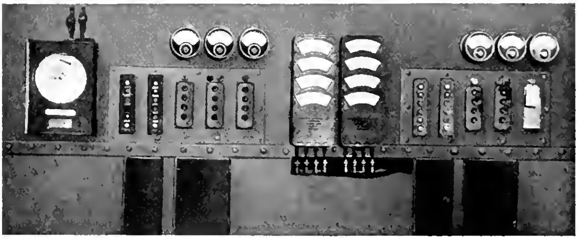


Fig. 10. Boiler Room Group Center Control of Auxiliaries for Two Boilers

contact with the segments and the pilot motor circuit is opened. A change in the draft in the opposite direction will repeat this cycle, except that the other finger and its corresponding segment make contact, the pilot motor reversing in direction thereby.

For push-button control, from either of two stations, it is necessary to throw one of the transfer switches to the "down" position. If both transfer switches are thrown down, or if two operators attempt to control the

saving in horse-power consumption is dependent upon the operating speed cycle. To illustrate the possibilities we have estimated that the motors will operate on a speed cycle as follows:

5 per cent of the time at 825 r.p.m.
35 per cent of the time at 570 r.p.m.
35 per cent of the time at 440 r.p.m.
15 per cent of the time at 380 r.p.m.
10 per cent of the time at shut down.

On this basis the total saving for each of these installations in kilowatt-hours per year for 365 24-hour days can be obtained from the curve titled "kilowatt-hours saving with brush-shifting motor," Fig. 12. Applying the cycle to this curve shows a saving in input per year of 147,000 kw-hr. Evaluating this at one cent per kilowatt-hour provides $1470 to cover the additional maintenance and investment charges of the brush-shifting equipment.

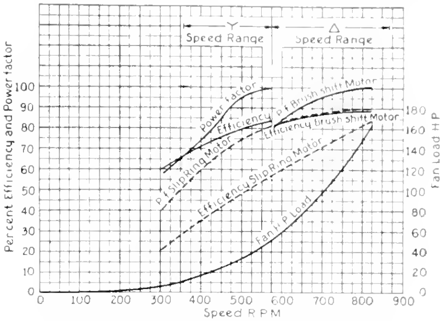


Fig. 11. Comparative Efficiency and Power-factor Curves of 150-h p., 720-r.p.m., and 150-h p., 900-r.p.m. Slip Ring Motor Under Actual Fan Load

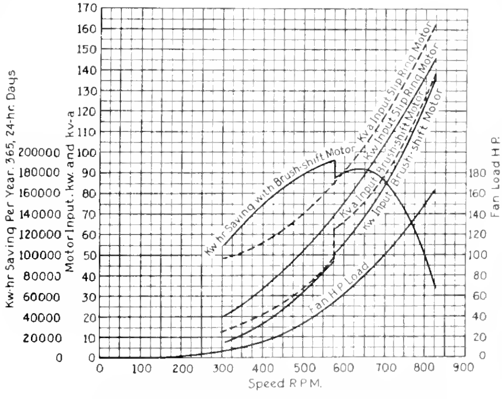


Fig. 12. Comparative Kw. and Kv-a. Input for 150-h p., 720-r.p.m., and 150-h.p., 900 r p m. Slip Ring Motor Under Actual Fan Load

Experience with motors of this type operating mine fans indicates that the life of brushes is from 10 to 12 months, while commutators require stoning every two to three years. The commutator of one such motor, for instance, has been stoned twice in five years of practically continuous operation.

The increased yearly maintenance costs inherent in this design over slip-ring motors can therefore be fairly accurately estimated as follows:

$1\frac{1}{3}$ sets of brushes	$160.00
$\frac{1}{2}$ cost of stoning commutator	10.00
Total	$170.00

This maintenance charge deducted from the evaluation of current saved leaves $1300 which, capitalized at 15 per cent for interest, depreciation, taxes, etc., would justify an additional expenditure of $8600 for this application.

The capability of delicate speed adjustment and elimination of bulky secondary resistances are additional advantages.

The actual cost of the brush-shifting equipments was approximately 75 per cent more than slip-ring induction motors and control; however, the former were very liberally designed and this ratio may be high for other installations.

Methods for the Production and Measurement of High Vacua

PART X. THEORY OF ADSORPTION AT LOW PRESSURES AND APPLICATIONS

By Saul Dushman

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The present installment discusses a new point of view of phenomena at low pressures which has been developed in recent years by Dr. Langmuir and which is of extreme importance for a proper understanding of experimental observations in this field. The next installment will contain further discussion of the applications of this theory.—Editor.

Theory of Unimolecular Layer

In the preceding installments of this series we have discussed the different methods for the measurement and production of high vacua. This discussion has to some extent involved a certain amount of theoretical consideration of the principles involved, but in the main the object has been to present the matter from an experimental point of view. The theory has been, as it were, a by-product of the experiments.

There has, however, been developed in recent years a point of view of low pressure phenomena which is of extreme importance for a thorough understanding of the significance of observations in this field.

Although Dr I. Langmuir developed this theory[1–2] as a result of his numerous investigations on the kinetics of chemical reactions at low pressures and the effect of these pressures on the electron emission from heated solids, he was also inspired in this viewpoint by the results obtained by Laue, the Braggs, and others, on crystal structure.

As shown by these investigators, the atoms in solid crystalline substances possess regular geometrical arrangements which correspond to the geometrical structure of the crystals themselves. Thus in a crystal of rock salt ($NaCl$), the atoms of sodium and chlorine are arranged at the alternate corners of a cube, each atom of sodium being surrounded by six of chlorine and each atom of chlorine by six sodium atoms. When salt crystallizes it therefore assumes the structure of a cube. In a similar manner A. W. Hull of this laboratory has more recently determined the arrangements of the atoms in a large number of metals.[3]

In order to account for this arrangement of atoms in solids Langmuir considers that there exists between these atoms both primary and secondary valence forces,[2] the latter differing from the former only in degree. It is therefore impossible to speak of a molecule of $NaCl$ in connection with a crystal of salt. The whole crystal constitutes a molecule whose composition is Na_xCl_x, where x is infinitely large. Only when the salt vaporizes do we have molecules corresponding to the formula $NaCl$ in the gas phase.

According to this point of view the layer of atoms constituting the surface of a solid would present unbalanced and unsaturated valencies on their outer side.

From well known thermodynamical considerations it follows that these atoms must tend to rearrange themselves so that the total energy in the field surrounding them is a minimum. In this manner we perceive that surface energy (surface tension of liquids also) is of the same nature as the energy of cohesion which holds the atoms together in the solid itself, and both cohesion and surface tension are to be regarded from this viewpoint as similar in nature to chemical forces. In fact, the distinction between so-called physical and chemical forces disappears on this basis. It would take us too far beyond the scope of the present discussion to mention the application which Langmuir has made of this suggestion to account for certain surface tension phenomena of liquids, but the subject is extremely interesting.[4]

As shown by Langmuir, "the attractive force between atoms in a solid becomes practically negligible when the distance between the centers of the atoms becomes

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[1] I. Langmuir, "Chemical Reactions at Low Pressures," J. Am. Chem. Soc. 37, 1139 (1915).

[2] I. Langmuir, "Constitution of Solids and Fundamental Properties of Solids and Liquids. Part I. Solids," J. Am. Chem. Soc. 38, 2221 (1916).

These papers contain the most comprehensive discussion of Langmuir's theory of adsorption and its bearing on other phenomena at low pressure.

[3] A. W. Hull, "The Positions of Atoms in Metals," Trans. Am. Inst. Elect. Eng., Oct. 10, 1919.

[4] I. Langmuir, "The Constitution and Fundamental Properties of Solids and Liquids. Part II. Liquids," J. Am. Chem. Soc. 39, 1848 (1917); also "The Mechanism of the Surface Phenomena of Flotation," Trans. Farad. Soc., 15, 1 (1920).

twice as great as the distance at which the atoms are in equilibrium." This smallness of the range of atomic forces compels us therefore to conclude that "in general the distance through which the surface atoms are shifted from their original positions in the solid is small compared to the average distance between the atoms. We must also conclude that the abnormal surface arrangement is usually limited to the surface layer only. The surface of a solid (or liquid) therefore does not contain, as is usually assumed, a transition layer consisting of several layers of atoms or molecules in which the density varies by continuous gradations from that of the solid to that of the surrounding gas or vapor. Instead we find that the change from solid to empty space is most abrupt. *The surface of a crystal must then consist of an arrangement of atoms as definite as that existing in the interior of the crystals, although slightly different from the latter. The surface must thus be looked upon as a sort of checker board containing a definite number of atoms, of definite kinds arranged in a plane lattice formation.** The space between and immediately above (away from the interior) these atoms is surrounded by a field of electromagnetic force more intense than that between the atoms inside the crystal."

The existence of this field of force at the surface (which as shown above is due to the fact that the atoms there have only part of their valencies satisfied) is according to Langmuir of fundamental importance in accounting for all the various phenomena that occur at the surface of a solid, such as the adsorption of gases, rates of chemical reactions, and the effect of gases on electron emission.

Adsorption is regarded from this point of view as the attachment of outside molecules or atoms to the exposed free valencies of the atoms comprising the surface layer. According to the kinetic theory of gases, the rate at which gas molecules come in contact with a surface is given by the equation

$$m = \sqrt{\frac{M}{2\pi RT}} \cdot p \qquad (1)$$

where m denotes the weight of the gas striking unit area per unit time, M is the molecular weight of the gas, R the gas constant, T the absolute temperature, and p the pressure.

Langmuir arrives at the conclusion that in almost all cases the molecules striking the surface *condense* on it. That is, there is practically little or no reflection.[5] "This holds true at all temperatures. The surface film so formed tends to be a continuation of the space lattice of the solid. On the other hand, evaporation of such a film is going on as an independent process, being so rapid at high temperatures as to keep the surface practically clean. Adsorption is a direct consequence of the time lag between condensation and evaporation, and is the result of the kinetic equilibrium."[6]

Previous investigators had concluded that at the surface of a solid we usually have present an *adsorbed film of variable thickness;* that, in fact, the adsorbed film may be a large number of molecules (or atoms) thick, and attempts have even been made to calculate the density of this condensed gas on the surface. According to this older theory the speed of a reaction between a gas and a solid would be limited by the rates of diffusion of the reacting gas molecules and reaction products through the film.

According to Langmuir, however, *the thickness of the adsorbed form is almost never in excess of one molecule (or atom)*, and the rate of a chemical reaction at the surface of a metal is therefore "limited not by the rate of diffusion through the adsorbed film, but rather by the rate at which the surface becomes exposed by the evaporation of single molecules from an adsorbed layer one molecule deep." Similarly, in the case of electron emission, the adsorbed film covering the surface to a larger or smaller extent tends to lower the emission, and the actual decrease depends upon the equilibrium between the rate of condensation and that of evaporation of the gas. At low temperatures, where the rate of evaporation is lower, the film covers a larger extent of the surface, and the decrease is therefore much greater, while as the temperature is raised, the area covered by gas molecules decreases and at very high temperatures the emission therefore tends to approach that of the metal in a very good vacuum.

In the following sections we shall discuss the application of this theory to the phenomena of evaporation, adsorption, and chemical reactions at low pressures.

Evaporation of Metals in Gases in High Vacua

As shown above, the rate at which molecules from a gas strike a surface is given by equation (1).

*The italics are due to the writer.
[5] I. Langmuir, "The Evaporation, Condensation, and Reflection of Molecules and the Mechanism of Adsorption," Phys. Rev. *8*, 149 (1916).
[6] J. W. McBain, "Theories of Occlusion, and the Sorption of Iodine by Carbon," Trans. Faraday Soc. *14*, 1 (1919).

When a solid is in equilibrium with its own vapor, at a pressure p, this equation must give the rate at which the atoms from the vapor strike the surface. On the other hand, since there is equilibrium there are just as many atoms evaporating per unit area per unit time as condense. Consequently, the above equation must give the rate of evaporation of the solid at the temperature T, so that by observing the rate of decrease in weight of a given filament at any temperature T, it is possible to calculate the vapor pressure at this temperature. In this manner, Langmuir has measured the vapor pressure of metallic tungsten over the range of temperature from 2000 deg. K. to 3540 deg. K.[7] and Langmuir and Mackay[8] have obtained similar data for the metals, platinum and molybdenum. M. Kundsen[9] has shown that the above equation also holds accurately for the case of a clean surface of liquid mercury evaporating into a good vacuum.

Langmuir and Mackay have also applied the same method to the determination of the vapor tension data in the case of the metals, iron, nickel, copper and silver, but have not published their results as yet. The method is so extremely simple that it ought to find a large field of application in the solution of certain metallurgical problems.

Adsorption at Low Pressures

The above theory leads to a precise definition of adsorption, as distinguished from absorption, occlusion and similar terms which are used quite loosely in the literature. We can speak of adsorption only as it relates to the gas which is condensed on the surface of any solid as a unimolecular layer. As stated above, adsorption is the direct result of a kinetic equilibrium between the rate of condensation and that of evaporation. "If the surface forces are relatively intense, evaporation will take place only at a negligible rate, so that the surface of the solid becomes completely covered with a layer of molecules. In the case of true adsorption this layer will usually be not more than one molecule deep, for as soon as the surface becomes covered by a single layer the surface forces are chemically saturated. Where, on the other hand, the surface forces are weak, the evaporation may occur so soon after condensation that only a small fraction of the surface becomes covered by a single layer of adsorbed molecules. In agreement with the chemical nature of the surface forces, the range of these forces has been found to be extremely small, of the order of 10^{-8} cm. That is, the effective range of the forces is usually much less than the diameter of the molecules. The molecules thus usually orient themselves in definite ways in the surface layer, since they are held to the surface by forces acting between the surface and particular atoms or groups of atoms in the adsorbed molecule."[10]

The evidence adduced by Langmuir in favor of this theory is of a three-fold nature. First, there are "the observations of the electron emission from heated filaments in various gases at low pressures and of the velocity of chemical reactions in gases at low pressures." Second, direct experimental evidence was obtained that "thin oil films on the surfaces of liquids, as well as absorbed films of substances dissolved in liquids do not normally exceed one molecule in thickness." Third, Langmuir has actually carried out measurements on the amounts of gas adsorbed on three typical surfaces: those of glass, mica, and platinum, at pressures ranging around 100 bars or less. The results of these latter determinations are in accord with the above theory. It must of course be realized that extreme precautions were taken in this investigation to have the surfaces thoroughly freed of previously adsorbed gases before letting them come in contact with the gas whose adsorption was to be measured. "At room temperature the adsorption by mica and glass was negligible, certainly not over one per cent of the surface being covered by a single layer of molecules. At −183 and −118 deg. C., relatively large amounts of gas were adsorbed, except in the case of hydrogen, and at the higher pressures used the surfaces tended to become saturated with gas. The *maximum quantities adsorbed even with saturated surfaces were always somewhat less than the amounts to be expected in a unimolecular layer.* The amounts of the different gases adsorbed by saturated surfaces of mica and glass were always in the following order: hydrogen, oxygen, argon, nitrogen, carbon monoxide, methane, and carbon dioxide. The adsorption of these gases was easily and quickly *reversible.*"

On the other hand, in the case of platinum no adsorption of gases could be observed at even −183 deg. C. until the platinum had been previously "activated" by heating to 300 deg. C. in a mixture of hydrogen and oxy-

[7] I. Langmuir, Phys. Rev. 2, 329 (1913).
[8] I. Langmuir and G. M. J. Mackay, Phys. Rev. 4, 377 (1914).
[9] M. Knudsen, Ann. Phys. 47, 697 (1915).
[10] I. Langmuir, "The Adsorption of Gases on Plane Surfaces of Glass, Mica, and Platinum," J. Am. Chem. Soc. 40, 1361 (1918).

gen. It was then found capable of adsorbing oxygen, carbon monoxide, or hydrogen, and the maximum quantities adsorbed corresponded to unimolecular layers. But the adsorption was not reversible, reactions apparently occurring on the surface "due to chemical forces of the primary valence type."

Before discussing the theoretical derivation of the relation between amount of gas adsorbed and the pressure observed in the above experiments, it may be well to point out the reasons given by Langmuir for the difference between these results and those observed by previous investigators on the adsorption of gases by charcoal and glass. "There appear to be three main reasons," he states, "which have led these investigators to conclude that adsorbed films are relatively thick. In most cases the experiments have been carried out with porous materials, such as charcoal, so that it has not been possible to determine with certainty the effective absorbing surface. Other workers have employed metal foil or other surfaces of known area, but in order to get sufficiently large surfaces have packed so much foil, etc., into small vessels that enormous numbers of capillary spaces were formed. They then employed saturated or nearly saturated vapors bringing about actual condensation of liquid in the capillary spaces. The third cause of error has consisted in the use of substances which actually dissolved the vapor thought to be adsorbed. The so-called adsorption of water-vapor by glass is an example of this kind."

In discussing, in a previous section,[11] the sorption of gases by charcoal and glass and also the gas evolution from glass and metals at low pressures, a number of observations have been mentioned which are in accord with this theory. It was mentioned in that connection that estimates have been made by various investigators of the effective surface per gm. of activated varieties of charcoal, and that on this basis, the largest amount of any non-condensible gas adsorbed by the charcoal would correspond to a layer less than one atom in thickness. Where the gas adsorbed is nearly saturated vapor (as is the case in a large number of the experimental observations), there is an actual condensation of liquid in the capillary spaces, so that in general we have, in the case of adsorption by charcoal, both condensation to liquid in the pores and true adsorption, or surface condensation.

It is, however, hardly fair to speak of "effective surface" in the case of any activated variety of charcoal. As has been pointed out by Langmuir,[2] "truly porous bodies, such as charcoal, probably consist of atoms combined together in branching chains of great complexity. The fibers of cellulose from which charcoal is usually formed consist of practically endless groups of atoms

H H H H
—C—C—C—C—
O O O O
H H H H

held together by primary valencies in the direction of their length and by secondary valence in the transverse directions. When the hydrogen and oxygen atoms are driven out by heat, the carbon atoms for the most part remain in their chains, but a certain number of cross linkages occur between these chains. *The porosity of the charcoal thus undoubtedly extends down to atomic dimensions.* The unsaturated state of the remaining carbon atoms explains the practical impossibility of removing the last traces of oxygen and hydrogen from any form of amorphous carbon.

"It is evident that with a structure of this kind, it is meaningless to talk about the surface on which adsorption can take place." On plane surfaces the maximum adsorption would correspond to a layer one molecule deep; but in the case of charcoal, there is no definite surface which can be covered by a unimolecular layer. The atoms of carbon would be separated by spaces which might hold one or more molecules of the gas, and on the other hand, these spaces might be too small to hold even one molecule.

It is of interest in this connection to mention a theory regarding the structure of charcoal which has been advanced by N. K. Chaney.[12] According to this theory "elementary carbon (other than diamond and graphite) exists in two modifications, '*active*' and '*inactive*' or *alpha* and *beta*. All 'primary' amorphous carbon consists essentially of a stabilized complex of hydrocarbons, adsorbed on a base of 'active' or *alpha* carbon. The active modification is formed whenever carbon is deposited at relatively low temperatures by chemical or thermal decomposition of carbon-bearing materials; in general below 500 to 600 deg. C. The inactive modification results from similar decomposition at higher temperatures, in general above 600 to 700

[11]See Parts VI and VII of this series, General Electric Review, Jan. and March, 1921.
[12]Trans. Am. Electrochem. Soc. 36, 91 (1919).

deg. C. The temperature at which molecular carbon is set free is apparently the controlling factor in determining whether it is of the active or inactive variety." The active form is characterized by a very high specific adsorptive capacity for gases. Chaney distinguishes between the true adsorptive capacity characteristic of the active form and a capillary capacity in virtue of which gas is taken up in pores formed by the loosely bound structure which results in carbonization of any carbon-bearing material, and he differentiates these as follows: On saturating an adsorbent and then noting the rate at which the gas is removed, it is observed that the portion absorbed in capillary spaces is given off readily while that adsorbed specifically is given off very slowly. "The weight of gas retained, after rapid weight loss has ceased, called the 'retentivity' of the adsorbent, is a measure therefore of the proportion of active carbon present, in a given weight of adsorbent. This test applied to pre-war charcoals shows that their adsorptive capacity is almost wholly capillary and dependent upon the physical structure left by distillation in the primary carbon. In general even this capacity is extremely small compared with present standards." The observation made by McBain[13] that the sorption of hydrogen by ordinary charcoal at low temperatures occurs in two stages finds an explanation from this point of view. The major portion of the gas was taken up very rapidly, while a residual portion required quite an interval of time to condense.

The problem in preparing active charcoal, according to Chaney, therefore consists in devising some method which will get rid of the hydrocarbons adsorbed specifically by the active carbon at the instant of formation. This adsorbed gas forms quite stable complexes with the carbon base and constitutes the product which he designates as primary carbon, "because it is the original product first occurring in low temperature distillation of carboniferous material." The methods of preparing active charcoal by oxidation with steam and other schemes therefore have for their purpose the removal of these adsorbed hydrocarbons.

In discussing the mechanism of the capillary and specific adsorptions, Chaney remarks: "The simplest theoretical assumption is that capillary adsorption is the filling of actual cells with liquid due to lowered surface tension, and dependent upon the size of capillaries, i.e., the physical structure of the adsorbent only. The specific capacity has been assumed to represent a field of force—probably due to unsaturated valencies—which is independent of a grosser physical structure of the adsorbent, i. e., it represents adsorption on a plane surface." That is, Chaney defines specific adsorption in the same manner as Langmuir and in accord with the latter's theory he finds that the amounts adsorbed in this manner do not exceed what would reasonably be expected for a layer one molecule deep. We shall see in a subsequent section that this theory of the mode of adsorption on active charcoal is in splendid agreement with the results obtained by Langmuir in studying the adsorption of oxygen by carbon filaments.

The sorption of gases by glass has been another case where, as Langmuir points out, actual solution of gases in the gel-like structure has been confused with true adsorption, and the experiments on the adsorption of gases by mica confirm this view.

Adsorption Relations

In 1909 Freundlich proposed[14] the semi-empirical relation between the quantity of gas adsorbed, q, and the pressure, p, at constant temperature, which has the form

$$q = k.p^{1/n}$$

where k and n are constants which depend upon the nature of both the adsorbent and gas, and n is greater than unity. This equation has been tested by a number of investigators and found to agree very badly with the observations when the range of pressures is large. For low pressures or high temperatures, where the quantities adsorbed are small the value of $\frac{1}{n}$ approaches unity, while at high pressures or low temperatures it often becomes as small as 0.1. These conclusions are well exemplified by the observations made by Claude and Titoff on the adsorption of gases by charcoal at various temperatures, and described in a previous section. Thus, referring to Table XVII, Part VI, of this series,* it will be observed that in the case of hydrogen $\frac{1}{n}$ is approximately equal to unity at all temperatures and pressures. On the other hand, in the case of nitrogen and carbon dioxide, $\frac{1}{n}$ decreases rapidly with increases in pressure and temperature

[13] Zeits. Physikal. Chem. 68, 471 (1909).
[14] Kapillarchemie, Leipzig, 1909.
* GENERAL ELECTRIC REVIEW, Jan. 1921, p. 61.

Quite recently A. M. Williams[15] has derived relations between the pressure, quantity adsorbed, and temperature by a combination of arguments based on thermodynamics and the kinetic theory of gases.

For the change in adsorption with temperature he obtains the relation

$$log\left(q.\frac{RT}{p}\right)=B+\frac{A}{T} \quad (2)$$

and for the adsorption isotherm, the relation

$$log\left(q\frac{RT}{p}\right)=A_0-A_1q \quad (3)$$

The latter may be expressed in the form

$$q/p=K\epsilon^{-A_1q} \quad (4)$$

where A_o, A_1, k, and c, are constants at any temperature. It will be observed that for small values of q, that is, small amounts of adsorption, the exponential term is practically unity, so that at low pressures and high temperatures, the latter equation reduces to the simple form,

$$q=k.p.$$

These relations are found by Williams to agree well with the observations mentioned above on the adsorption of gases by charcoal, especially those of Miss Homfray. The kinetic theory considerations used in deriving the above relations lead Williams also to interesting conclusions which are in agreement with Langmuir's theory. He finds on this basis that the surface area of the charcoal used by Miss Homfray was about 130 sq. meters per gram of adsorbent, which appears reasonable in view of the fact that activated charcoal has an estimated surface area of about 2500 sq. meters per gram. Furthermore, the theory enables Williams to determine the range of molecular attraction between adsorbent and gas, and he finds this to vary from 3.2 to 4.1×10^{-8} cm., that is, of the same order as the molecular diameter. As already stated, Langmuir arrives at the conclusion that these forces must diminish to practically zero at distances which are twice as great as the distance at which the atoms are in equilibrium. The agreement in conclusions arrived at from totally different points of view is certainly striking.

As discussed above, Langmuir's theory regards adsorption as the result of a kinetic equilibrium between the rate of condensation and that of evaporation. On this basis the quantitative form of the adsorption isotherm, that is, the relation between amount adsorbed and pressure, at constant temperatures, depends upon the nature of the mechanism of both the condensation and evaporation. Langmuir points out that "the surface of crystals resembles to some extent a checkerboard, and when molecules of gas are adsorbed by such a surface these molecules take up definite positions with respect to the surface lattice and thus tend to form a new lattice above the old. A unit area of any crystal surface, therefore, has a definite number of 'elementary spaces,' each capable of holding one adsorbed molecule or atom. There will frequently be cases where there are two or three different kinds of spaces. * * * Each kind of elementary space will, in general, have a different tendency to adsorb gases. As the pressure of gas is increased the adsorption will then tend to take place in steps, the different kinds of spaces being successively filled by the adsorbed molecules." The phenomena that may be met in the study of adsorption are thus quite varied and may often be very complex. It is therefore not to be expected that one single equation should cover all cases of adsorption. As an illustration of Langmuir's mode of reasoning we shall discuss his derivation of the adsorption isotherm for the simplest case of adsorption, that in which we have only one kind of elementary space and in which each space can hold only one adsorbed molecule.

The number of gram-molecules striking unit area per second is, in accordance with equation (1) above,

$$\mu=\frac{m}{M}=\frac{p}{\sqrt{2\pi MRT}} \quad (1a)$$

A certain fraction of these molecules, which we may call α, will condense. Consequently, the rate of condensation on a bare surface is $\alpha\mu$. If θ represents the fraction at any instant of the surface which is bare, the *rate of condensation* of gas on the surface is $\alpha\theta$. Similarly the *rate of evaporation* of molecules from the surface at this instant is $\nu\theta_1$, where $\theta_1=1-\theta$ is the fraction of the surface covered with molecules, and ν is the rate of evaporation from a surface completely covered.

At equilibrium,

$$\alpha\theta\mu=\alpha(1-\theta_1)\mu=\nu\theta_1$$

Let us place

$$\frac{\alpha}{\nu}=\sigma$$

Then

$$\theta_1=\frac{\sigma\mu}{1+\sigma\mu} \quad (5)$$

[15] Proc. Roy. Soc. (Edin.) 39, 48 (1919).
Proc. Roy. Soc. (London) 287 (1919).

But we can write θ_1 in another form. Let N_0 denote the number of elementary spaces per unit area. Then, if q denotes the number of gram-molecules of gas adsorbed per unit area of surface,

$$q=\frac{N_0\theta_1}{N}$$

where $N=6.062\times10^{23}$, the number of molecules per gram-molecule.

Substituting for θ_1 by means of equations (5) and (4a) it follows that

$$q=\frac{abp}{1+bp} \qquad (6a)$$

where

$$b=\frac{\sigma}{\sqrt{2\pi MRT}}$$

and

$$a=\frac{N_0}{N}$$

It will be observed that for small values of b, that is large values of ν, the above equation tends to approach the form

$$q=abp$$

That is, when the rate of evaporation is very high (at higher temperatures) and low pressures, we have the linear relation between q and p.

In order to test equation (6a) Langmuir writes it in the form

$$\frac{p}{q}=\frac{1}{ab}+\frac{p}{b} \qquad (6b)$$

so that by plotting $\frac{p}{q}$ against p, the slope of the straight line gives $\frac{1}{b}$, that is, $\nu\frac{\sqrt{2\pi MRT}}{\alpha}$.

In nearly all cases, the value of α is practically unity. Hence it is possible to calculate from the observed values of b at any temperature the rate of evaporation per unit area. In the experiments with mica and glass, Langmuir finds that this relation is in good accord with the observed data for all the gases tested. His conclusions with regard to the thickness of the adsorbed film have already been discussed above.

Instead of calculating the rate of evaporation, Langmuir has calculated the values of $\sigma=\frac{\alpha}{\nu}$ for the different cases. The physical significance of this quantity is that it expresses the "relative life" of the molecules on the surface. Thus for oxygen adsorbed on mica at 90 deg. K., $\sigma=97{,}000$ seconds, while at 155 deg. K., $\sigma=69{,}000$ seconds. In a similar manner it is possible to calculate from the vapor tension data the relative life of a molecule at the surface of liquid oxygen at any temperature. A comparison of the values of σ thus calculated for the gases in the adsorbed state and the same gases in the liquid state shows that the relative life in the first case is anywhere from 10,000 to over 1,000,000 times as great as in the latter case. "The forces involved in the adsorption of these gases are thus very much more intense than those holding the molecules of the liquids together."

In a similar manner Langmuir derives relations for other cases of adsorption. An interesting case is that in which the gas is adsorbed as atoms (e.g. hydrogen by palladium); it is shown that under these conditions, the amount adsorbed must vary as the square root of the pressure even at relatively low pressures.

It is evident that in the case of porous substances, such as charcoal, no simple adsorption relation can hold valid, since we can not speak of any definite surface, and furthermore, depending upon the magnitude of each individual space in such a structure, the rate of evaporation of adsorbed gas will vary tremendously.

Evidence for Adsorption Theory from Study of Chemical Reactions at Low Pressures

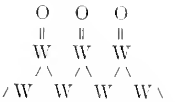
Most interesting evidence for the unimolecular layer theory of adsorption has been obtained by Langmuir in his numerous investigations on chemical reactions at low pressures. Some of these investigations have been mentioned in a previous section in discussing chemical methods of clean-up. The interest in the present connection lies rather in the conclusions which Langmuir has derived regarding the mechanisms of these reactions.

Let us consider the reaction between *oxygen at low pressures and a heated tungsten filament*. At any temperature of the filament it is observed that the rate of clean-up is proportional to the pressure. From this rate it is possible to calculate the value of ϵ, the ratio between the number of molecules of oxygen disappearing per unit time and the number that strike the filament in that time. Table I shows how ϵ varies with the temperature.

TABLE I
RATE OF CLEAN-UP OF OXYGEN

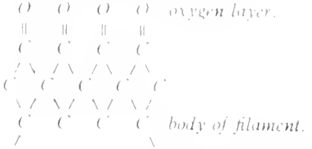
Temp., Deg. K.	1070	1270	1470	1570	1770
ϵ	0.00033	0.0011	0.0053	0.0094	0.0255
Temp., Deg. K.	2020	2290	2520	2770	
ϵ	0.049	0.095	0.12	0.15	

It is evident that ϵ is always less than unity, but tends to approach this value with increase in temperature. In order to form the oxide WO_3, at least two molecules of oxygen must react with each atom of tungsten on the surface, and from considerations based on the kinetic theory of gases, Langmuir concludes that the manner in which this reaction occurs is as follows: The tungsten atoms on the surface adsorb oxygen atoms forming a layer which may be represented thus:



That is, oxygen atoms are held on the surface by means of primary valencies from the tungsten atoms. Oxygen molecules striking this layer combine with the group WO to form WO_3 which immediately distills off as a single molecule. The layer of oxygen combined with tungsten atoms on the surface is extremely stable. It will not react with hydrogen even at 1500 deg. K. This means that the surface of tungsten at this temperature is completely covered with a layer of oxygen one atom deep, and the presence of this oxygen acts as a catalytic poison for the reaction between hydrogen and oxygen. In a similar manner when a tungsten filament is heated in a mixture of carbon monoxide and oxygen, none of the CO reacts with the oxygen even with the filament temperature as high as 2800 deg. K., but the oxygen attacks the tungsten filament at the same rate as if CO were absent.

In view of what has been stated above regarding the structure of active charcoal and its high capacity for adsorbing gases, the experiments on the reaction between *oxygen and carbon* are extremely interesting. "Experiments with carbon filaments in oxygen, and in carbon monoxide or dioxide, have shown that oxygen acts as a catalytic poison, on the reaction between oxygen and carbon, and on that between carbon dioxide and carbon dioxide and carbon. It was also proved that this poisoning effect is due to a remarkably stable film of adsorbed oxygen, so stable in fact that the filament must be heated in a good vacuum for nearly half an hour at 2300 deg. K. in order to distill it off. In this case there is very clear evidence that this film consists of oxygen atoms chemically combined by primary valences to the carbon atoms forming the body of the filament, according to the formula"



With carbon dioxide evidence was obtained that the reaction occurs as follows:

$$CO_2 + C = CO + CO$$
(gas) (adsorbed in carbon).

The reaction between *carbon monoxide and oxygen in contact with platinum* is another illustration of the catalytic effect of an adsorbed film. The rate of clean-up in this case was observed to be directly proportional to the pressure of oxygen, but inversely proportional to the pressure of carbon monoxide. In order to account for this Langmuir assumes that the reaction occurs when CO molecules strike oxygen on the surface, but does not occur when O_2 molecules strike CO on the surface. Thus CO acts as a catalytic poison for the reaction at a platinum surface.

It is evident that this theory must exert a profound influence on our views of the phenomena of catalysis, a subject of immense importance in chemical technology, and there is no doubt that an application of Langmuir's theory to this field is going to bring about practical results of great value.

Evidence for Adsorption Theory from Study of Effect of Gases and Thorium on Electron Emission of Tungsten

The effect of gases in decreasing the electron emission from heated metals has been studied in some detail by Langmuir[16] [17] and the observed phenomena are strikingly accounted for by the theory of adsorbed films one molecule in thickness. In fact, there is a remarkable similarity between the effect of these films in poisoning the catalytic activity of a filament and in decreasing the electron emission.

Thus oxygen and water vapor, which react with a tungsten filament forming an adsorbed layer of oxygen atoms, both lower the emission enormously even at very low pressures (0.001 bar). By observing the rate of decrease of emission when gas is let in, and the

[16] "The Effect of Space Charge and Residual Gases on Thermionic Currents in High Vacuum," Phys. Rev. 2, 450 (1913).
[17] "The Electron Emission from Tungsten and the Effect of Residual Gases," Phys. Z. 15, 516 (1914).

rate of increase of emission when the filaments are heated in vacuo it is possible to study the rate of formation and also the rate of evaporation of these films at various temperatures. "The fact that the rate of evaporation of these films even at temperatures of 1800 deg. K. is slow enough to measure proves that they are remarkably stable."

Nitrogen lowers the emission only when voltages high enough to cause ionization are used in measuring the electron currents. The positive ions formed by bombarding the nitrogen molecules with electrons form an adsorbed film on the surface of the filament and thus lower the emission. On pumping out the nitrogen and heating the filament to a high temperature this film gradually distills off and the emission returns to its normal value.

Interesting effects are obtained with tungsten filaments containing small amounts of thorium. If such a filament is heated in a very high vacuum to 2900 deg. K. for a short time and the electron emission at 1800 deg. K. is then measured, it is found that the emission is the same as that of pure tungsten. By now heating the filament a few minutes at about 2200 to 2300 deg. K., the electron emission at 1800 deg. K. is found to have increased over 10,000 fold, if the vacuum is very good. This effect is accounted for on the theory that thorium forms an adsorbed layer on the surface of the filament. At 2900 deg. K., the thorium, which is much more volatile than tungsten, distills off and leaves a surface of pure tungsten. At 2300 deg. K., the rate of evaporation of thorium is fairly low, but the rate of diffusion through the tungsten is sufficiently high to allow the accumulation of thorium atoms on the surface, while at 1800 deg. K., the rate of diffusion is so low that no more thorium comes to the surface. By studying the rate of increase of the emission at temperatures between 1800 and 2300 deg. K., and the rate of decrease of emission at temperatures above 2300 deg. K., it is possible to obtain data on the rates of diffusion and of evaporation of the thorium.

If a pure tungsten filament is adjacent to the thoriated filament and the latter is heated to a temperature at which the thorium evaporates fairly quickly, it is found that the pure tungsten filament gradually assumes the same electron emitting activity as the thoriated filament and there is very strong evidence that a layer of thorium one atom deep gives just as high an emission as a layer several atoms deep.

The effect of gases in lowering the emission of thorium is even more pronounced than in the case of tungsten. An adsorbed oxygen layer on the surface of thorium is so stable that it does not distill off unless the temperature of the filament is raised to 2900 deg. K.

Similar phenomena have been observed in studying the effect of gases on the photoelastic activity of metals and there is no doubt that in all these cases adsorbed films play an important role in decreasing the electron currents.

(To be continued)

The Electrical Operation of the River Rock Gravel Company

By A. V. Thompson

San Francisco Office, General Electric Company

This article describes the most modern and best equipped plant of its kind in the West. As electricity is used exclusively in all operations, the author presents such information as will interest those who operate similar plants in whole or in part by power other than electricity. The article contains a complete description of the electrified method employed in excavating the material, transporting it, and preparing the finished product.—Editor.

The plant of the River Rock Gravel Company is located on Tesla Creek seven miles south of Tracy in central California, where the river channel breaks from the Coast Range and spreads into the west rim of the San Joaquin Valley.

This creek or arroyo is a natural drainage channel where rains are infrequent. The gravel deposits extend fifteen miles up the channel from the washing plant into the Coast Range. When heavy rains come, generally during January, February, and March, floods rush down this arroyo carrying thousands of tons of sand, gravel, and boulders which tend to replenish the materials that have been excavated during the preceding dry period. Such heavy downpours may not come more frequently than once every third or fourth season; and it is not infrequent to have periods of drought of seven to eight months' duration, which affords opportunity for the removal of sand and gravel from the stream bed without interruption by high water.

The quality of sand and gravel for construction work is determined by freedom from solubles and also by the degree of irregularity of contour of the particles, sharp edges being desirable. The solubles are eliminated by thoroughly washing the sand and gravel at the washing plant. As the geological formation in this locality is of recent origin, the second qualification is supplied by nature, the small rocks having sharp edges in distinction to the smooth and well rounded surfaces of rocks which have been subject to a longer period of water wear.

The material as taken from the creek or arroyo is colloquially known as "dirt" or "bar run" and in various parts of the channel varies in compactness and in the proportions of sand, gravel, and boulders.

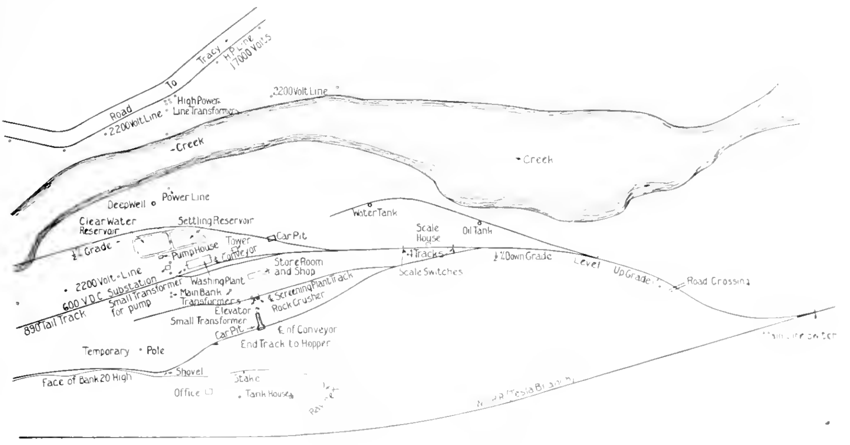


Fig. 1. Map of the River Rock Gravel Company's Plant

Process

The dirt is dislodged from the creek bed by an electric drag-line excavator. From the bucket of this excavating machine the material is loaded into a "grizzly" car, the large boulders being eliminated in the process of loading. This car is hauled by an electric locomotive over a standard-gauge railroad to the dumping pit at the washing plant. From the dumping pit the material is fed onto a belt-line conveyor which carries it to the highest point in the washing plant. Upon dropping from the belt-line conveyor, it is classified as follows:

Large material for gyratory crusher (3-in. grizzly).

Medium size for disc crusher (1 5/8-in. conical screen).

Balance of material for conical screens and classification in storage bins.

Fig. 2. General View of Tesla Creek Channel, showing Electric Drag-line Excavator in the Foreground, Railway Running to Washing Plant in the Distance and Storage Piles in the Vicinity of Washing Plant. The flat level country of the San Joaquin Valley is seen in the background

The crushed materials from the gyratory and disc crushers are fed onto separate belt-line conveyors to independent conical screens. This conveyor system is so arranged that materials from any of the bins in the main washing plant may be fed onto the belt for mixing purposes from the bottom or ground level of each bin. The mixed material, or crushed rock, can then be discharged directly into bins for loading on cars for storage or shipment; or the crushed rock may be fed back onto the main belt-line conveyor for processing and to the appropriate bin in the main washing plant.

The assortment of finished materials is as follows, being determined by the perforations in the conical screens:

(1) Gravel 1 to 1½ in.
(2) Gravel ½ to 1 in.
(3) Gravel ¼ to ½ in.
(4) Sand to ¼ in.
(5) Crushed rock ¼ to 5/8 in.
(6) Crushed rock 5/8 to 1¼ in.
(7) Crushed rock 1¼ to 1¾ in.
(8) Cementing road gravel.

The mesh of the first conical screen is 1 5/8 in. Everything between 3 in. and about 1½ in. goes into a bin to be fed into disc crushers. The material from the crushers is fed back onto the main belt if larger than 1¾ in. and into bins if smaller. Water spray plays on each conical screen and not only washes the material but assists in moving it to the next revolving screen.

All materials from the washing plant are loaded into standard gondola cars for shipment or for storage. These cars are moved by an electrically operated locomotive crane to the main-line track for shipment or to the storage piles where they are unloaded by the crane. The crane also serves to load cars from the storage piles for shipment.

Electrification of Haulage System and Crane

With the increasing price of fuel oil and the statements of the best authorities that no great reduction in price could be looked for, the fact that electric power was giving uniform satisfactory results on the main drives of the washing plant and that power was available, led to the electrification of the locomotive and crane which makes this a 100 per cent electric plant. Under steam operation considerable trouble had been experienced from shut-downs and expensive repairs had been caused by bad boiler water and the scarcity of skilled labor during the war period.

General Scheme of Power Distribution

Three-phase, 60-cycle, 17,000-volt power is purchased from the Sierra and San Francisco Power Co. A bank of three single-phase transformers steps down the incoming voltage to 2300. At this distributing voltage, lines run to a portable bank of transformers on a truck which serves 440-volt power to the drag-line excavator that at some future time may operate as far as one mile from the washing plant. The line from the portable transformer bank to the drag-line excavator is carried in a flexible water-proof armored cable. The electric shovel has a bank of 2300/400-volt transformers as a part of its equipment. Three-phase power at 2300 volts is also supplied to the motor-generator station for providing direct-current power at 600 volts to the third-rail haulage system.

Third-rail System

Every known system of haulage was carefully studied and the 600-volt direct-current third-rail contact system was adopted as being the best suited to meet the local conditions.

The first condition prescribed by the plant operators was that no overhead obstructions would be permissible as the drag-line excavator would be required to operate at any point on the haulage system in the channel and the locomotive crane would operate at any point in the washing plant yard and on the shipping spur and car storage tracks. The booms of both equipments require an unobstructed sweep from both sides of the tracks and over them.

The fact that considerable discarded track rail was available for the construction of the third-rail, and that overhead clearance was required for gravel handling equipment as well as loading cars from chutes at the washing plant bins, made this choice of contact system the logical one. The results of experience have shown this system to be an extremely simple one to install with ordinary track labor.

As soon as it was decided to electrify, the track gang was instructed to replace every fifth tie by one a foot longer than used for standard gauge. The third-rail was located $26\frac{3}{4}$ inches from the gauge line of the adjacent running rail and 6 inches above it. This location gives a liberal clearance from the standard main-line equipment which is used for haulage and shipment of materials.

As the track ballast is gravel, and seven or eight months may elapse without rain, the hazard from contact by workmen is greatly reduced. Suitable protection has been installed at points in the washing plant yard and at the dumping pits. As main-line train crews occasionally switch in the plant yard, an electric section switch is provided at the yard limit, and the third-rail so sectionalized that the portion of track over which such crews are switching may be de-energized.

As the drag-line excavator is working progressively up the creek channel, the contact system lends itself readily to extension. The excavator prepares the track roadbed. The track gang lays the ties, track, and installs the third-rail insulators on extended ties. The train crew, consisting of locomotive operator and brakeman, mounts the third-rail on blocks and installs temporary bonds. Time is given for this work while the drag-line excavator is loading the grizzly car.

The locomotive is provided with a reel and 200 feet of cable which extend the operating zone of the loading point 200 feet beyond the end of the third-rail. The use of the cable also makes it unnecessary to install third-rail in the vicinity of the loading point where large boulders falling from the grizzly car might damage the insulators, the third-rail, or its protection in the vicinity of grade crossings.

At storage piles it is found advisable to install bulkheads about 18 inches above the roadbed to prevent the spilling of materials against the third-rail. This protection also makes it easier for the crane operator to load materials from the storage piles to the cars as it acts as a guard to prevent the bucket from grounding the third-rail when material is being picked up from a point close to rail.

As the maximum distance of haulage to the washing plant was uncertain at the time the system was being designed, as considerable light rail might be used in the third-rail construction, and as temporary bonding or no bonds on either running or third-rail might have to be resorted to at times, the highest practical direct-current voltage adaptable to the required locomotive and crane equipment was adopted; viz., 600 volts.

Electric Drag-line Excavator

The electric drag-line excavator is equipped with a $1\frac{1}{2}$-yard bucket, a 95-h.p. hoist motor, a 50-h.p. swing motor, and a manual remote-control panel. Both motors are of the 3-phase

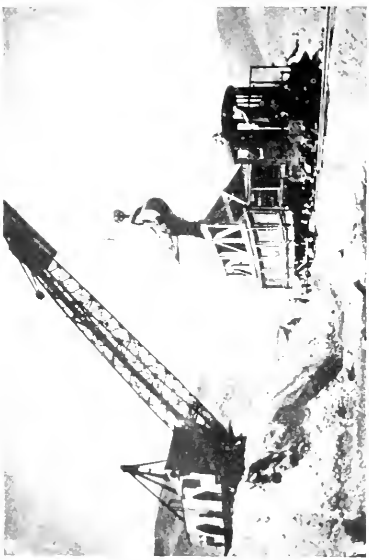


Fig. 3. Electric Drag-line Excavator Loading Grizzly Car with Electric Locomotive in Foreground. Two members of the track gang may be seen grading and laying track just ahead of the grizzly car

Fig. 4. View of Electrified Steam Locomotive Crane Unloading Cars to Storage Piles

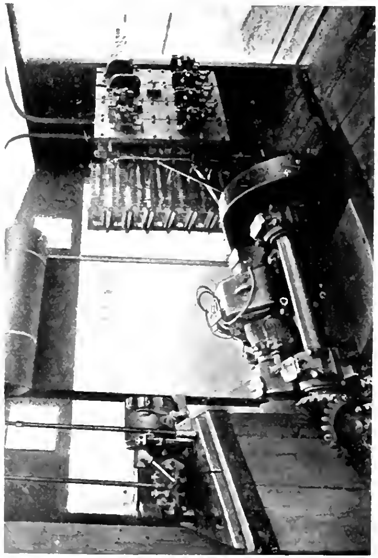


Fig. 5. The Motor, Control Board, Resistors, and Air Compressor of the Electrified Locomotive Crane

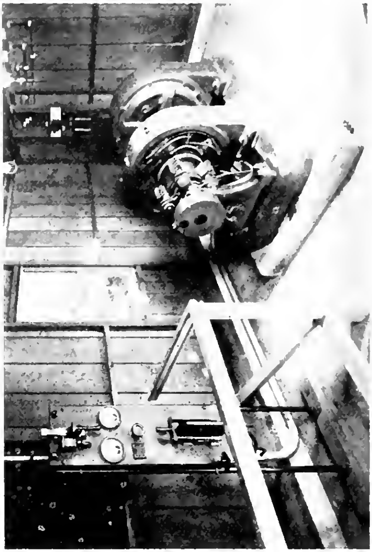


Fig. 6. Interior View of Substation, Showing 150-kw. 600-volt Motor-generator Set and Switchboard

60-cycle 440-volt variable-speed type. This equipment has been in almost continuous service for seven years. Its radius of operation, and its flexibility in handling and loading material is very much greater than is possible with a shovel-type excavator.

Grizzly Car

The grizzly car is a standard gondola with a super-structure on which are mounted inverted sections of 56-lb. T-rails. The rails are placed at an angle of approximately 45 degrees with the horizontal, and the clearance distance between rails is about seven inches. This clearance is determined by the largest boulders which may pass through the gyratory crusher. The car has a capacity of about 50 tons of gravel.

Electric Locomotive

It was difficult to prescribe a definite set of service conditions for the electric locomotive that was to haul the grizzly car between the drag-line excavator and the washing plant. The track conditions might be mucky and the spill from loaded cars might accumulate on the rails so as to block the movement of loaded cars during the critical periods of acceleration. The length of haul and the grades might exceed those prevailing at the time the original study was made to ascertain the proper locomotive equipment. The isolated location of the plant, and the fact that no reserve locomotive would be available, led to the adoption of conservative capacities.

The locomotive selected is of the 12-ton 56½-in. gauge single-truck type and is equipped with two 65-h.p. motors, controllers, combined straight and automatic air-brake equipment with an air compressor having a capacity of 15 cubic feet of free air per minute, cable reel and automatic reeling equipment including 200 feet of single-conductor cable, two third-rail shoes, and other necessary auxiliaries.

An air hose is arranged on the brake system of the locomotive to permit of ready cleaning from time to time. When the wind conditions are such as to blow dust on the locomotive when the grizzly car is being loaded, the locomotive is uncoupled and moved a short distance away.

The present length of haul from the drag-line excavator to the washing plant is so short as to permit of the locomotive, in its layover time, moving cars in the washing plant yard. This service was previously performed by a steam locomotive crane at the extremely low speed of ½ to 1½ miles per hour. The quickened service afforded by the electric locomotive permits of a more efficient use being made of the electrified crane for loading and unloading cars.

Electric Shovel

The electric shovel, used occasionally to dig a special grade of road gravel, is equipped with a 2½-yard bucket, 2300/440-volt transformers, and 60-cycle variable-speed motors of the following capacities: hoisting motor 115 h.p.; crowd motor 50 h.p.; and swing motor 50 h.p.

Direct-current Substation

The direct-current substation contains a 100-kw. motor-generator set consisting of a 2300-volt 3-phase 60-cycle induction motor direct connected and mounted on same base with a 100-kw. 600-volt direct-current generator. The set is controlled from a panel having the necessary instruments and switches.

Locomotive Crane

The locomotive crane has been converted from steam to electric operation and is used for moving cars in front of the loading chutes of the washing plant, for loading and unloading cars at the storage piles, and for moving cars from the washing plant yard to the main-line spur for shipment.

In studying the plans for the electrification of this steam operated crane, the problem resolved itself into the following features:

- The actual work required of the crane and locomotive functions.
- The mechanism of the crane and methods of operation.
- The dismantling of the steam equipment to be discarded.
- The selecting of appropriate motors and control.
- The locating of the motors and control equipment.
- The locating of the connecting shaft between the motor and the crane main driving shaft.
- The determining of the gear ratio between the motor armature and the main driving shaft of the crane mechanism.
- The mounting of collector rings on the crane turntable and the running of power circuits from the third-rail shoes to the collector-ring brushes.

The providing of an air supply for use with the old steam brake equipment.

The reballasting of the crane turntable to compensate for the changes in weight and location of the equipment.

Performance

The following service conditions were decided upon as being typical, after actual observations were made and conservative averages determined.

The spotting of three standard gondola cars with a trailing load averaging 83 tons

Fig. 7. Locomotive Showing Operation of Cable Reel and Method of Operating Electric Locomotive for Distance of 200 Feet Beyond the End of Third Rail

total and a maximum of 165 tons total at a speed of one-half mile per hour; the train to move 70 feet maximum at this speed in one direction and then return; and this operation to be repeated with power on for 10 seconds and off 30 as an average condition. The loading and spotting of the three cars will take from 30 to 40 minutes. The train will move on a level tangent track in good condition. The loaded cars will then be moved about 100 feet on level tangent track at a speed of one mile per hour. The locomotive crane will be uncoupled and will give the cars a slight push, after which they will run down grade coasting for a distance of 500 feet to the main-line railroad shipping point.

Another class of service is the moving of materials from bunkers to storage piles. In this case one or two cars, averaging 55 tons and a maximum of 110 tons during spotting, will be moved as previously described except that the time for spotting and loading will be reduced 20 to 25 minutes. The distance which the cars move during spotting and loading will be the same, i.e., 70 feet.

After loading, the train will move about 100 feet on level tangent track at a speed of one mile per hour and then down a one-half per cent grade of tangent track at a speed not exceeding two miles per hour.

Upon arrival at the storage piles the crane and bucket feature go into action and the following typical cycle of duty is performed:

Bucket with maximum load	11,200 lb.
Bucket with average load	9000 lb.
Lifting speed	115 ft. per min.
Average distance lifted	18 ft.
Closing of bucket on load	8 sec.
Returning of bucket	10 sec.
Dumping load	4 sec.
Average swing of boom	45 deg.
Average direct-current voltage	550 volts
Average weight of material in cars to be unloaded	40 tons

After the cars are unloaded they are moved back up the 1½ per cent grade for a distance of 500 feet at a speed of 1 to 1½ miles per hour, and the spotting and loading operation is repeated. There is a 15-minute average layover between the cycles of duty described, although this may be as low as five minutes for a ten-hour day and longer when plant conditions are normal.

Crane Mechanism

The original steam equipment of the locomotive crane included a two-cylinder (10-in. bore, 10-in. stroke) engine having an original rating of 100 h.p. at 300 r.p.m. and a 60-h.p. boiler at 125 lb. per sq. in. but operating at an average pressure of 90 lb. per sq. in. The ratio between the engine drive shaft and the truck axle was 6½ to 1.

As the steam engine was non-reversible, the reverse operation of the various crane and locomotive functions was accomplished through clutches. The "tag line" drum was mounted on a friction which must revolve in only one direction to keep a steadying pull on the line running to the bucket frame. When planning the electrification, a non-reversible control was adopted so that no change in the handling of the clutches would be made to confuse the operator. The only change in the operating mechanism of the original equipment was in the design of the main driving shaft. The original shaft had an extension beyond the supporting bearings for crank pins. The replacing shaft is similar in all respects inside the bearings, the shaft extension on one end being eliminated while the extension on the other end has a seat for the bevel gear which meshes with the pinion on the connecting shaft that is geared to the back shaft of the motor.

The removal of the engine, boiler, oil and water tanks, and steam piping provided a liberal space for the installation of the electrical equipment and the mechanical connections between the motor and crane.

Selection of Motor and Control

A series motor and semi-automatic control was adopted as being the most suitable for the overall performance of the crane. While it was appreciated that it would be possible for the operator to unclutch the load from the motor while the power was on, this condition was not considered to be serious because the motor would be permanently tied in to the back shaft, the connecting shaft, the main crane driving shaft, which in turn is permanently geared to all the clutch shafts. The noise of this gearing when racing would give an audible warning in the event that full voltage was applied to the motor without clutched load. The identical principle had applied to steam operation and the handling of the throttle. The motor is equipped with a speed-limit switch which opens the control circuit and drops out all the power contactors when the armature attains a speed 15 per cent over that at rated horse power.

The control equipment is arranged to give positive power on the first and second notches. If the controller is moved beyond to the third, fourth, and fifth notches, additional contactors will not come in until the current has fallen to a predetermined point on each notch. The current relays on the contactors controlling the automatic points are adjustable over a wide practical range. If the circuit breaker trips, it is automatically reset by moving the controller to the "off" position. The controller is mounted so that the handle is in practically the same position as the old steam throttle.

Location of Motor and Control Equipment

As the boiler and fuel tanks occupied a greater space than is required by the motor and other electrical equipment, the main point in determining the layout was to place the weight as far out on the cab underframe as possible to give the maximum counterbalancing effect to the boom side, to give easy access for inspection and maintenance, and to make the floor plan as spacious as practical for the operator.

Since without extensive change in the original crane machinery it was not possible to gear the motor directly to the main driving shaft, a connecting shaft was used making it possible to place the motor in the most convenient location.

Gear Ratio

The electrification of the locomotive crane was worked out in conjunction with the original designers, they advising the layout of the connecting shaft and bearings, and the location of the motor feet to the underframe members. The gear reduction from the motor to the back shaft and the main driving shaft of the crane was also determined by them, after a careful study of the energy and speed of the main shaft required to fulfill the service conditions. It was the duty of the motor and control designers to calculate the energy at the bucket, turntable, and locomotive axles, and upon the assumption of mechanical losses back to the motor, check this energy against the characteristic of the

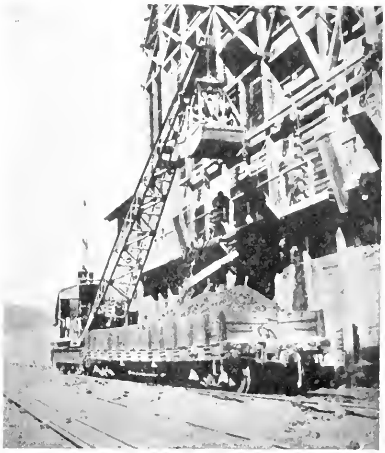


Fig. 8. Electric Locomotive Crane Moving Cars for Loading in Front of Washing Plant Chutes

motor selected and the energy it is capable of delivering at various speeds.

The gear reduction from the motor to the back shaft is 3⅓ : 1. The bevel pinion on the back shaft has 24 teeth driving to a 24-tooth gear on the motor end of the connecting shaft. The pinion on the crane end of the connecting shaft has 31 teeth and the gear on main driving shaft has 17 teeth bevel gearing. The diameter of the connecting shaft is 3½ inches. A bearing and thrust collar is mounted at each end of the connecting shaft.

Turntable Collector Rings and Brushes

Two cast-iron collector rings and suitable brushes were installed to complete the circuits from the third-rail shoes to the revolving turntable. The rings were mounted on simple wood supports on the main or stationary underframe of the crane and in a position concentric to the center post or support of the crane turntable. The brushes were mounted on the turntable. The collector rings and brushes are similar to those furnished with locomotive crane equipment made originally for electric operation. There are two steel-spring-actuated brushes or shoes per ring, located at points diametrically opposite, so that any tilting of the turntable incident to operation will not break the connection.

Air Supply for Brakes

As the crane was originally operated, steam was used for braking purposes. Compressed air on the renovated equipment is furnished by an electrically driven air compressor having a capacity of ten cubic feet of free air per minute, and rated for 45-minute operation per hour at 600 volts. An electric governor switch cuts in the compressor at 65 pounds and out at 75 pounds per square inch. An air reservoir and whistle are also provided. The original steam brake valve and piping is retained.

Plant Operation

An observer on the top of the washing plant watches the height of the various grades of material. The bins are numbered and when full a large number is displayed at a conspicuous place for the information of the yard gang. Empty cars are then brought to the proper chutes, are loaded, and moved to the storage piles and unloaded or the material held in the car for shipment.

The comparatively short period of operation of these equipments by electricity prevents an extended analysis and comparison with previous steam operation, but the period has been sufficiently long to make apparent the advantages in favor of electrical operation.

A survey of the plant failures when the locomotive crane and the locomotive were steam operated shows that the slackening in the plant output and the chief cause of overtime were directly attributable to boiler and steam equipment troubles. Since the complete equipment has been electrically operated, no delays have occurred which could be attributed to electrical failures and no overtime has been necessary for which electrical failures were responsible. The hostling of the locomotive crane and locomotive has also been completely eliminated. Without regard to the time of day or night that it might be desirable to start up the plant, no preparation now has to be made so far as power requirements are concerned.

The operators of the locomotive crane and locomotive are highly pleased with electrical operation. In hot weather, which attains extreme temperatures, the comfort of the operator is increased. There are no gauge glasses or boiler to need attention. A given controller position always produces similar power conditions. When steam was used, the operators were constantly kept on their nerve by the continual rising and falling of the pressure necessitating their "feeling" for the load by manipulation of the throttle. This advantage of electricity over steam is particularly noticeable on the steam locomotive crane where the operations of swinging, closing bucket, lifting and swinging, and swinging and lowering are carried on in rapid succession and some of the operations simultaneously in which case the operator puts his controller on a given point, removes his hand, and is thus allowed two hands to operate the clutches and brakes. Experience has shown the proper point on the controller for each operation and they follow in rapid succession.

The elimination of stand-by losses is important. In variable load work, with coal or oil as fuel and where the operator cannot give his undivided attention to boiler pressure and feed water, the natural tendency is to always play safe and "have her blow off" rather than be handicapped by low boiler pressure. Oil firing lends itself to variable steam demands better than coal, but even with oil fired locomotives and cranes it is safe to say that fifty per cent of the fuel is burned in maintaining the boiler pressure when not needed for actual operation. Prior to electrification, oil was burned at the rate of 238 bbl.

(10,000 gal.) per month, the oil costing $1.70 per bbl.

Data

Electric locomotive supplanted the steam locomotive February 20, 1919.

Electric crane equipment supplanted the steam crane equipment, May 27, 1919.

Overtime for hostling steam locomotive and crane:

2 hours per day for locomotive at $0.55 per hour	$1.10
1 hour per day for crane at $1.00 per hour	1.00
	$2.10

This hostling charge amounted to $54.60 per month or $655.20 per annum.

Washing out locomotive boilers and cleaning flues (estimated)	$20.00 per month
Washing out crane boilers and cleaning flues (estimated)	$20.00 per month
	$40.00

This charge amounted to $480.00 per annum.

Saving per annum by eliminating fuel oil	$4048.00
Saving per annum by eliminating hostling	655.20
Saving per annum by eliminating washing and flue cleaning	480.00
Total	$5183.20

The details of actual maintenance costs of the steam locomotive equipment have not been kept but some of the features of maintenance may be used as an index to the conditions.

Retubing of locomotive boilers	$400.00
Retubing of crane boiler	$500.00

Loss of time of locomotive and crane equipment when taking fuel and water was 1½ hours in 18 machine hours.

Conclusion

A knowledge of the performance of this class of electrical equipment in other places makes it safe to assume that for several years to come the maintenance will be limited to the following:

- Brake shoe maintenance
- Third-rail shoe maintenance
- Brush and small electrical contact renewals
- Journal brass and motor-bearing renewals.
- Miscellaneous renewals such as incandescent lamps.

Concerning the matter of operating cost, Mr. A. D. Schindler, consulting engineer of the property, furnishes the following interesting information:

"During the five months from October, 1919 to March, 1920, inclusive, which period is fairly representative of general results, the plant manufactured 67,420 tons. The total power bill for that period covering the entire operation was $1,510.43, a unit cost of 2.24 cents per ton. During the corresponding period of the previous year the bills for power, fuel oil, and locomotive repairs amounted to $3,028.88. No record was kept of the tonnage manufactured during this time. The assumption is made, however, that the tonnage was the same as that of the year following, on which basis the unit cost for power would be 4.5 cents per ton or practically twice that of the later period. As a matter of fact, the production during the earlier period was probably considerably less than is assumed, which would raise the unit cost to a still higher figure."

A Transition Period in Radio Communication

PART I

By A. F. Van Dyck

Radio Engineering Department, General Electric Company

Radio development has advanced by a series of steps rather than by a steady progress. The present transition period results from the application of comparatively recent inventions and improved methods which have enlarged the general scope of the art to a heretofore undreamed of degree, have made wireless telephony practical, and have placed radio at last on a reliable basis of operation by displacing from the equipment those elements which at times were erratic in behavior. In the first installment of this article, which is based upon a paper delivered by the author before the Pittsburgh Section of the A.I.E.E., these recent developments are described. In the next and concluding installment are explained their effects upon the several divisions of radio communication, the conditions in each as they stand today, and the possibilities when the new epoch is firmly established.—Editor.

Arts and sciences usually develop in such manner that their progress, when reviewed, is apparently divided into well-defined epochs, each of which has been terminated, and the next begun, by some radical discovery or change in line of thought. Naturally when arts are young, these epochs are short in time of duration. In radio, in its single score of years, we can number four epochs to date.

One of the valuable characteristics of the last epoch is that interest in radio has led to considerable familiarity with its principles and practice on the part of all electrical engineers. This will be taken advantage of in this article to describe recent technical advances in radio apparatus which have brought about another epoch in this new branch of the electrical industry.

The past epochs may be characterized as follows: First, Marconi's simple apparatus with vertical aerials and series spark gap, and on the receiving end, the coherer; second, the introduction of coupled circuits and the use of syntony, the use of alternating current for supply power, and electrolytic and mineral detectors; third, the rotary spark gap together with the advantageous increase in supply frequency to 500 cycles; and fourth, the quenched gap, arc transmitters, vacuum-tube detectors. In the twenty years of radio practice, these four epochs average five years' time in duration. In other words, a radical change in apparatus has occurred every five years. This is important to notice, not because of historical interest only, although an appreciation of this will give a valuable background to the picture of radio progress, but because it is indicative of what can be expected in the future. The inventions which brought new epochs into radio were not made at the beginning of the respective epochs, but were invented in the first ten years or so. Their full realization in practice however was dependent upon a gradual appreciation of their merits, as we never find the general service inception of a new principle or new device until a considerable time after its conception. This is of course largely due to the fact that commercial factors militate against a change in apparatus too often. As it is, radio equipment is replaced more quickly than probably any other form of electrical installation because of its rapid improvement; and the longer the life obtained from an equipment, the more economical will be the radio maintenance cost. This fact receives little consideration from the radio engineer usually, since he is anxious to see every

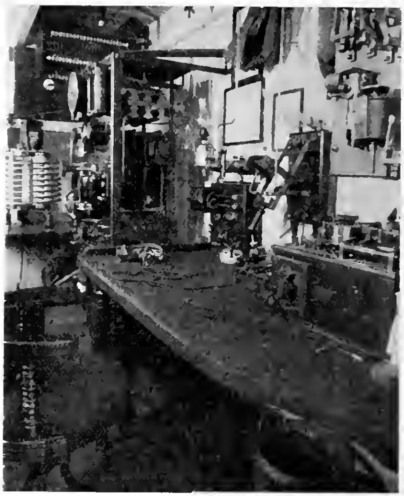
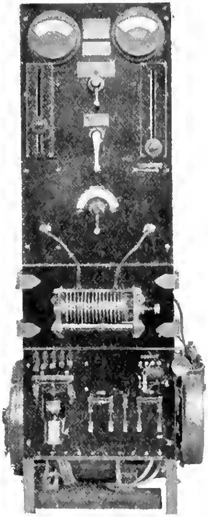


Fig. 1. Typical Ship Radio Installation of Ten Years Ago

installation brought to the maximum efficiency made possible by each new improvement and is not directly responsible for the economical maintenance of service. Furthermore, many users of radio equipment, not including the transoceanic or the military, are satisfied with equipment which fulfills the minimum law requirements, and do not demand improvements until their advantages are demonstrated very clearly. It is of assistance to consider these factors when studying the effect of the developments which are exerting influence at the present time.



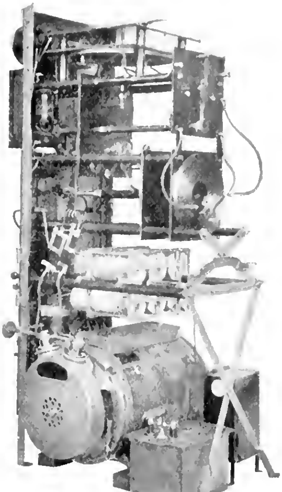


Fig. 2. Front and Back Views of Two-kilowatt Spark Type Transmitter, Standard for Ships for the Past Eight Years

We are now at the beginning of another epoch, where certain radical changes are commencing to appear in general service, which will upset the conceptions of the possibilities and general economic usefulness of radio that were becoming familiar to and established in the public mind. This article will attempt to point out and discuss some of the factors in this change.

Most important among these developments is the three-electrode vacuum tube, which has profoundly affected every branch of radio practice. The diverse and manifold uses of this single fertile device are really marvelous to consider. It is not exaggeration to say that every one of the new possibilities of radio accomplishment is due to it, in one or another of its various uses. The use of the vacuum tube as a generator of radio-frequency power is a revolutionary development, since in addition to providing a new and convenient continuous-wave source, it is easily adaptable to radio telephony. Radio telephony over useful distances, up to the time of this discovery, was a commercial impossibility simply because all the methods for production of continuous radio-frequency power were not adapted by any known means to speech control by microphones, which has been the only practical means up to the present for transforming sound energy into electrical energy. Telephony by radio was therefore waiting for this development, so to speak, and can now without serious technical handicap enter into commercial use and development.

In addition to the use of the vacuum tube as a radio-frequency power source, there is its use in reception as a detector, that is, to operate from received radio-frequency energy some indicating device which by reason of physical limitations is a low-frequency or direct-current device. The vacuum tube is the best detector known at present because it is more than a rectifier as were previous detectors, being more like a relay in which the

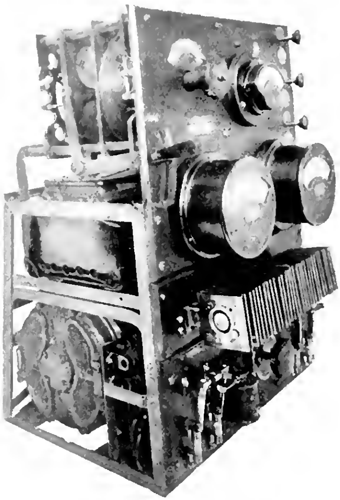


Fig. 3. Spark Transmitter, One-half Kilowatt Navy Type, Used on Small Craft Such as Sub-chasers

incoming energy controls and actuates a local source of energy. This fact makes it at once the most sensitive detector and the most stable.

Also, the vacuum tube is used as amplifier for both reception and transmission purposes. In this application, energy obtained from a given source can be increased, from local sources, by millions of times. Any sort of relay is an amplifier, but the point of importance in the vacuum-tube amplifier is, first, that it can function at radio frequencies without any time lag, and second, that its inherent lower limit of sensitiveness below which it will not function at all is extremely low compared with mechanical and other known relays. The most minute electrical impulses can be raised to useful magnitude. This is naturally of great aid in radio reception where received energy is so very small. The vacuum-tube amplifier is also useful in other electrical work than radio. It is sure to become a powerful tool of the scientist for the study or the measurement of small electrical forces, and will certainly bring advancement in many branches of the electrical field, as it has already in wire telephony when used as a repeater. Incidentally it is interesting to note that investigation of the vacuum tube has thrown much light on the study of the theory of electricity and matter in general.

In summary of the general vacuum-tube innovations, there are the facts that in radio reception it is a better detector than previous ones, and that it will amplify voltages of any frequency, thereby increasing sensitiveness of receiving apparatus, and in radio transmission, the provision of a sustained radio-frequency generator of such form that its output can be interrupted for telegraph transmission or modulated for telephone transmission by simple and totally effective methods.

The next development of large influence is the radio-frequency alternator. Although direct generation of radio-frequency voltage by an alternator is fundamentally the simplest way of obtaining it, many years had to be spent in development work to solve the mechanical problems involved in generators to deliver such frequencies. Happily, these problems have been solved, and the Alexanderson alternator is available in sizes as large as are necessary for transoceanic communication. The result is that we have a means of generating radio power for use in long-distance work, which is free from the objections which applied to previous methods. The alternator is not suitable for the higher radio frequencies such as are used in small stations for shorter distances, and is best suited to the high-power fixed-frequency stations where its advantages are most needed.

Other types of alternators than the direct type, which generate a fundamental frequency of a few thousand cycles only and depend upon tuned circuits or other means for exaggerating a harmonic of the fundamental frequency, have been used; but the direct type, generating the frequency which is desired, is the only one at present satisfactory in all respects. It is probable that the Alexanderson alternator will continue to be the best generator for high-power work until vacuum tubes of large output are developed.

Along with the alternator there have been developed means of control of its output by ferro-magnetic methods, applicable both to telegraphy and telephony. This control in itself is an important addition to radio practice.

Next we come to improvements in methods of reception. The first major factor which has contributed to these improvements is the vacuum-tube detector and amplifier, which renders reception possible under conditions undreamed of a few years ago. Whereas in the former epoch, antennas hundreds of feet high were found necessary to obtain the required received energy from foreign stations to operate the detector, now it is possible when no stray disturbances are present to receive transatlantic signals on a coil aerial a foot square. So that, as far as sensitiveness is involved, no further improvement in radio reception is necessary to obtain any results which may be reasonably desired. For instance, in experiments to demonstrate this, signals received from European stations have been amplified sufficiently to operate an automobile horn, whereby signals can be read at any distance to which the horn can be heard. Similar received signal energy has been so disposed as to actuate high-power transmitting stations in this country, so that the operator in Europe whenever he pressed the key operated a station on this side and heard himself sending, his signals having crossed the ocean twice.

Unfortunately, however, sensitiveness is not the only requisite to satisfactory radio reception. It will be noticed that, although these ultra sensitive receiving devices have been known and in use for a few years, it has not been possible to reduce materially the power which is used in transmission, at least over large distances. This is due to the fact that "strays," sometimes called "atmospherics" or "static," are a very serious factor in reception. The second improvement in reception lies in the development of circuits for the reduction of strays, and in these circuits the most marked departure from former technique is found. The general procedure followed in the several systems developed and now used consists in the use of long, low antennas, not that such lengthy energy collectors are necessary from the energy standpoint (as shown in the preceding statements) but because the fundamental idea is to provide an energy collector whose dimensions are comparable with the dimensions of the wave to be received. Interference from strays is the determining factor in sizes of transmitters today, for just as the usual electric light and power generating system is required to have enough capacity to meet peak demands, so is the radio transmitter compelled to have many times the power which would be necessary if stray interference could be avoided. This means that the elimination of interference from

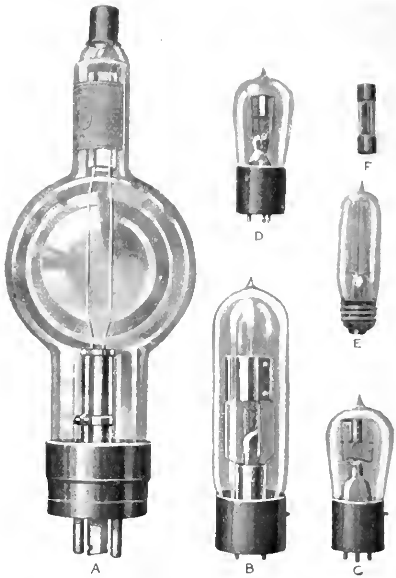


Fig. 4. Vacuum Tubes of Sizes from 5 to 250 Watts Power Output

strays is the most important fundamental radio problem today. Its complete solution would make it possible to communicate with powers a hundredth part of those now used; and the reduction of transmitter power necessary would decrease the interference produced at one station by others, and fuller advantage could be taken of the extraordinary sensitiveness of receiving apparatus as it is today. Powerful amplification alone does not answer, for the most troublesome types of strays are of the same nature as the signals, and are amplified in much the same proportion as are the signals. This problem received much attention in the early days of radio, but its complex and difficult character led to discouragement, and a feeling of hopelessness among radio engineers was quite general until recently the work done by Weagant showed that the problem was not hopeless. In this respect radio is at the same stage of development that wire telephony passed through when it overcame the difficulties of cross-talk. Many said at that time that it would never be satisfactory to install circuits as near together as was necessary to meet practical installation requirements, but of course this difficulty has been overcome completely.

Fig. 5. Radio Set for Aircraft, Vacuum Tube Transmitter and Receiver Combined in One Unit

The causes of strays are not thoroughly understood, and are most difficult to investigate because strays are so very erratic in behavior. The character of stray interference is complicated, varies from month to month, day to day, and even from hour to hour. This, in addition to the facts that the sense of hearing must be relied upon mainly, and a repetition of conditions cannot be obtained at will, makes the study of reception improvement a very tedious performance. The complete solution of the problem will cause another radical change in radio practice which will probably be the next epoch in the art. Improvement is being obtained by improved detector circuits and vacuum tubes, and it seems likely that the eventual elimination of strays will be accomplished partly by the form of the antenna and partly by the form of the detector.

A factor in the recent radio advances, and one which will have increasing influence, is the entry of a large number of engineers and scientists into radio work in the last few years. This fortunate occurrence was due to the war and would probably not have transpired had not the technical innovations which have been mentioned been made just at the beginning of the war. The technical advances enormously enlarged the military application of radio and it was required that radio devices of various new kinds, based on the new discoveries, be developed and manufactured as quickly as possible. Since the number of engineers occupied in radio was inadequate to the demand, it was necessary to turn to those in the most closely allied electrical branches for assistance. The fascination of radio—which as has been remarked by someone, has many of the characteristics of a disease—has been felt by these men, and most of those who came into close touch with radio work during the war retain their interest. Consequently we have today power engineers, physicists, and research investigators actively engaged in radio. The result has been the application of new lines of thought, giving great benefit to the radio art, in addition to the large and sudden increase in the number of technicians engaged on its problems.

Fig. 6. Vacuum Tube Transmitter of Medium Power

(To be Continued)

The Largest Electric Steel Furnaces

By J. A. Seede

Power and Mining Engineering Department, General Electric Company

The electric steel furnaces described in this article represent a ten-fold increase in capacity over the first commercial electric steel furnace placed in operation in the United States fifteen years ago. The rapid growth in the size and number of installations of the electric furnace is due to the superior qualities of its product. This is obvious from the fact that the Charleston electric furnaces are charged with molten metal from open hearth furnaces which prior to the introduction of the electric furnace produced some of the highest grade of steel available. The success of these latest and largest furnaces justifies us in predicting that we shall soon see electric furnaces of two or three times their capacity.—Editor.

To France we all accord the honor of being the birthplace of the modern electric steel refining furnace, chiefly through the work of Dr. P. L. T. Heroult, but the United States is in a position fully as well established in electric furnace development and application.

The tapping of the first heats from the two 40-ton Heroult steel refining furnaces at the U. S. naval ordnance plant, South Charleston, W. Va., on February 2, 1921, marked a considerable step forward in the electrometallurgy of steel and iron, and consequently is of great interest and value, not only to the electrical engineer, chemist and metallurgist, but, in this specific case, to those concerned in the manufacture and application of ordnance and armor.

In the early days of electric steel furnace development there were conflicting opinions respecting the relative merits of arc and resistance heating, and this difference of opinion continues to the present time. The arc furnace, however, steadily demonstrated its superiority for general work and soon outdistanced the induction furnace in number and output. This relationship may be changed in the future for special applications, as the 2-ton furnace, Fig. 11, recently completed a run of 555 heats on one lining at the Pittsfield Works of the General Electric Company. This is an exceptional performance, specially when we consider that each heat consisted in melting high silicon steel scrap on a magnesite lining; but as the desired results could

Fig. 1. The Two 40-ton Heroult Electric Furnaces at the Charleston, W. Va., Naval Ordnance Plant. Furnaces are shown in tilted position immediately after pouring

not be obtained in any other way it was necessary to follow this apparently incongruous practice. Assuming that the same results could be obtained with the arc furnace, the lining cost of induction furnace is considerably below the single item of electrode cost in the arc furnace while the figures for power consumption are comparable.

The first commercial electric furnace in the United States for melting and refining steel was a single-phase, 4-ton 2-electrode equipment installed at the Halcomb Steel Company, Syracuse, N. Y., from which the first heat was years of operation, the generating equipment was replaced by a 500-kv-a. transformer taking power from an 11,000-volt, 25-cycle circuit. Later on this transformer was replaced by a 900 kv-a. transformer, the increase in power being in line with developments up to the period referred to.

The original Thury regulator, after a long period of successful operation succumbed to the wear inevitable in a steel plant and was replaced by a General Electric electrode regulator in which the voltage and current were both used to control the electrodes. It is

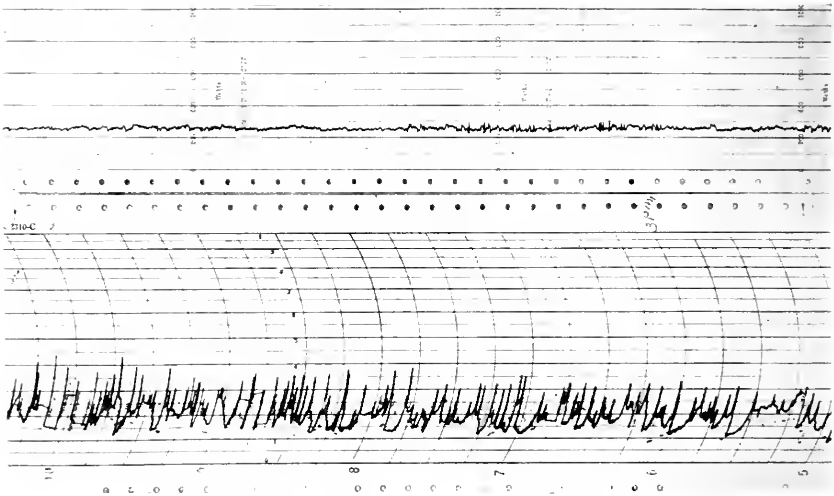


Fig. 2. A Comparison Between Automatic and Hand Control of Furnace Electrodes. Upper curve shows kilowatt input with automatic control and lower curve kilowatts input with hand control

tapped on April 5, 1906. Other important installations of the Heroult furnace in the United States were:

Location	Capacity	Date When First Heat Was Tapped
Halcomb Steel Co.	4 tons	April 5, 1906
Illinois Steel Co.	15 tons	May 10, 1909
Carnegie Steel Co.	25 tons	November 17, 1916
U. S. Naval Ordnance Plant	40 tons	February 2, 1921

The Halcomb furnace was supplied with power from a 60-cycle, single-phase, General Electric generator driven by a reciprocating steam engine. After approximately eleven

interesting to note that Siemens used an automatic regulator in his experiments of 1880, recognizing at that early date the necessity of eliminating the human element in controlling the power and allowing the operator the fullest benefit of this source of heat in his metallurgical operations. Even

Fig. 3. Another View of 40-ton Furnace, Showing Control Panels on Right and Electrode Motors on Platform Above

with this splendid example of foresight, there still exist those who believe there are some objections against automatic control, such as higher cost, but the superiority of the automatic control is graphically illustrated by Fig. 2, which shows a wattmeter record

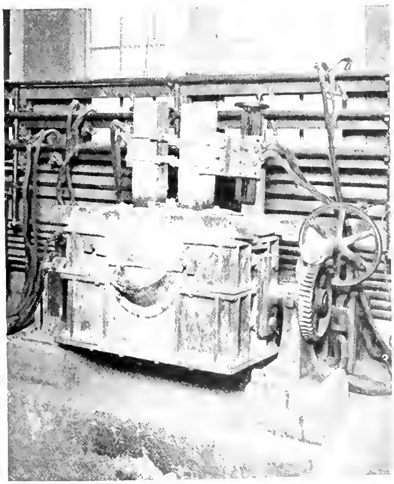


Fig. 4. Experimental Steel Furnace Built About 1907 by the Research Laboratory from Odd Parts. This furnace had a capacity of 600 lb. steel. Two 8-in. square carbon electrodes were used, and power input amounted to as much as 200 kw. with voltages up to 90

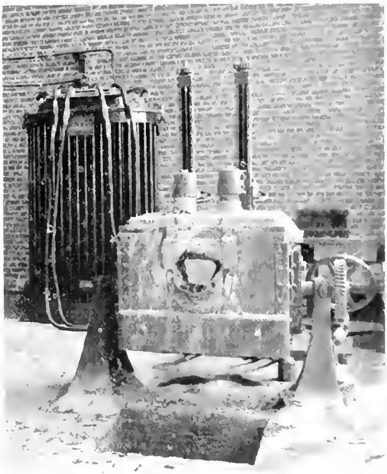


Fig. 5. The Results Obtained with the Furnace of Fig. 4 Were so Encouraging That the Design was Improved as Shown in This Illustration. Several of these furnaces are still in use, mainly for experimental work

of two furnaces of the same design making the same product, the upper curve showing the good results of the automatic control while the lower shows the bad results of hand control.

Several electric steel furnaces have been built and operated at the Schenectady Works

Fig. 6. Two-ton Three-phase Electric Arc Furnace Developed at the Schenectady Plant About 1908. At the time it was the largest capacity electric steel furnace in existence

and extensive research has been conducted in the development of satisfactory control equipment, transformers, switches, cables, etc This research has placed the Company's engineers well in advance of commercial electric steel furnace practice and they were well prepared to specify and design the electrical equipment for the two 40-ton Heroult furnaces at the South Charleston naval ordnance plant when the order for this equipment was received.

These furnaces are operated in conjunction with two 75-ton basic open hearth furnaces using natural gas of 950 1000 B.t.u., and after dephosphorizing the molten steel is transferred to the electric furnace to be desulphurized, deoxidized, and brought to the final temperature.

Due to using a considerable quantity of scrap from the electric furnaces, the molten steel coming from the open hearth furnaces occasionally goes as low as 0.009 per cent phosphorous and 0.008 per cent sulphur. The phosphorous content is not changed by the electric furnace but the sulphur content on rare occasions is reduced to 0.006 per cent. The steel is tapped from the electric furnace at a temperature of 1650 deg. C., and is then poured from the ladle into the ingot molds through a 2-in. nozzle. It is of interest to note that the metal losses, including slag losses, handling metal, etc., in the open hearth furnace are 8 per cent to 12 per cent, while in the electric furnace they are ½ to 1½ per cent. Both open hearth furnaces are being operated with basic linings at the present time, but on account of the purity of the scrap from the electric furnace product it is possible that one of the open hearth furnaces will be operated with an acid lining, in which case final treatment in the electric furnace may not be necessary for part of the product

The metallurgical results are justifying the selection of the electric furnace for this important task, the quality exceeding all expectations.

Each furnace is normally rated at 40 tons holding capacity, each charge being handled separately so as to keep the metal clean as possible, and large ingots will be formed from two ladles through two runners. One of the

Fig. 7. An Improved Form of the Furnace Shown in Fig. 6. Furnaces of this type are still in service at Schenectady

furnaces is fitted with 24-in. carbon electrodes and the other with 14-in. graphite electrodes, thus giving current densities of 46.8 and 137.5 amperes per square inch respectively with the transformer at its maximum output of 21,200 amperes per phase. On the basis

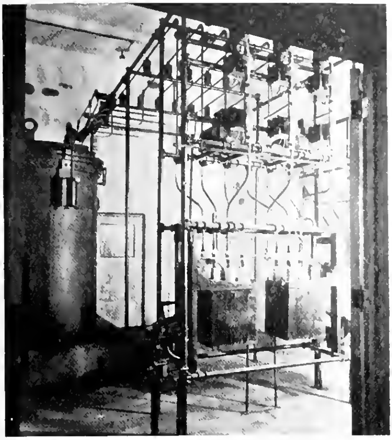


Fig. 8. One of the Transformers, with Its High-tension Switching Equipment, for the Forty-ton Steel Furnace

of 2500 kv-a., giving 13,130 amperes per phase, the heat generated in a 100-in. length of electrode is respectively 21.6 kw. and 28.3 kw., amounting to 1 per cent and $1\frac{1}{3}$ per cent of the total input respectively on the basis of 85 per cent power-factor, a small amount but contributing to the total useful heat in the furnace.

The electrical equipment for each furnace consists of one transformer, one switch and instrument panel, one electrode regulator panel, one operator's panel and three electrode motors and a tilting motor.

Each transformer is of the 3-phase water-cooled oil insulated type, supplying 17,300 amperes per phase, with 110 volts between phases, or a total of 3300 kv-a., the high voltage winding being designed for operation from a 6600-volt, 3-phase circuit. Taps are provided in the high voltage windings so that full input can be obtained at 100 or 90 volts as desired, the last connection giving 21,200 amperes per phase. Although not the largest 3-phase transformer built by the General Electric Company for electric furnace work, it is unusually well adapted for this particular furnace installation.

A similar transformer is shown in Fig. 10. For transformers of such large current capacity the efficiency of 98.2 per cent is still high enough to indicate a very careful electrical design.

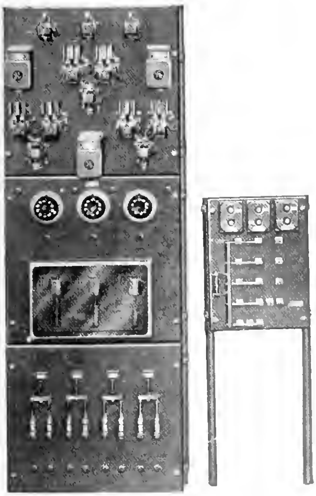


Fig. 9. General Electric Automatic Control Panel for Electric Furnace Electrodes. Operator's panel on right

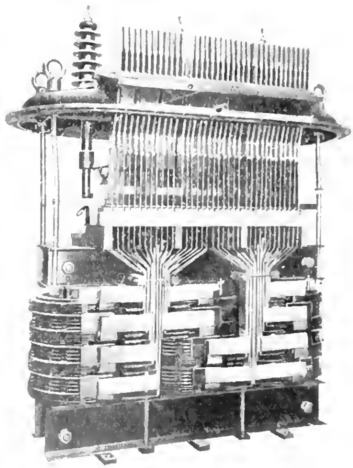


Fig. 10. High Capacity Transformer of the Type Supplied for the 40 ton Electric Furnace. Note the coil and core construction and the general sturdiness

Each switchboard consists of a switching and instrument panel, an automatic regulator panel and an operator's panel. On the instrument panel are mounted three ammeters,

Fig. 11 Induction Type Furnace at Pittsfield Works, Which Has Recently Completed 555 Heats on One Lining

one voltmeter, one indicating and one curve-drawing wattmeter, one watthour meter, and one power-factor indicator, together with various relays and switches for controlling the solenoid operated 15,000-volt, 500-ampere oil switches.

The automatic electrode regulator is so well known as not to require description; and the same is true of the operator's panel.

The tilting motors are of 35-h.p. capacity at 725 r.p.m. and take power from a 230-volt direct-current circuit. They are provided with drum controllers for reversing and with solenoid brake.

The electrode motors, whose important duty it is to control the movement of the electrodes in response to the action of the electrode regulator, are designed to deliver 5 h.p. at 1150 r.p.m. when taking power from a 230-volt direct-current circuit. They are totally enclosed and provided with self-lubricating bearings.

All the electrical equipment used with these furnaces is practically standard and it is a comparatively simple matter to increase the capacity when circumstances decide that such action is necessary. It is not difficult to picture installations in the immediate future containing units of double or treble this capacity, perhaps having six or more electrodes and becoming more and more effective against its only real competitor, the open hearth furnace.

Using Ohm's Law to Integrate

By M. D. Cooper

Engineering Department, National Lamp Works of General Electric Company

The device described in this article, which employs the well known principle of Ohm's law, was devised to facilitate the calculation of the average light produced by incandescent lamps throughout life. By means of this device this calculation has been speeded up four-fold, which represents a material saving in time and expense when the performance of thousands of lamps annually has to be determined.—Editor.

The fact that the voltage drop in any section of an electric circuit can be expressed as the product of the resistance of the section and the current passing through it has been applied in what is believed to be a new way in the design of an electrical device for the computation of the average ordinate of a jagged curve between observed points. The method was devised to simplify the work of determining from test data the average light output of incandescent lamps throughout life. The electrical calculator reduces the time to one-fourth of that required by an experienced computing machine operator, and the saving is considerable when it is considered that computations must be made on from 25,000 to 30,000 lamps annually. It will be seen that the method is applicable to a very wide variety of uses.

The obvious method of computing the average ordinate of an area under a curve through observed points is to sum up the areas of the trapezoids included between a section of the curve, the base line, and two ordinates. The area of each trapezoid is, of course, equal to one-half of the product of the base and the sum of the two side ordinates.

In this electrical computing device, the products are secured by passing a current proportional to one factor through a resistance proportional to the other factor. The resultant voltage drop is then proportional to the product. As applied to the area of the trapezoid, a current proportional to the width is passed through two resistances in series, proportional respectively to the two side ordinates, whence the voltage drop is proportional to the area of the trapezoid. Electrical addition of these drops sums up the total area under the curve, and electrical resolution of the total drop into a product of resistance times current serves to resolve the area into the product of base times mean ordinate.

Incandescent lamps are tested at voltages higher than normal in order to shorten the time required for life test. Well established conversion factors permit the results to be readily expressed in terms of normal lamp life. The test life rarely exceeds 275 hours. At intervals throughout the test, the lamps are photometered and the lumen output is recorded. The data of Table 1 are typical.

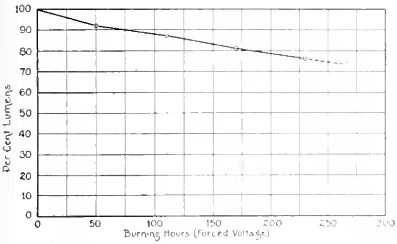


Fig. 1. Typical Performance Data on an Incandescent Lamp

TABLE 1

TYPICAL PERFORMANCE DATA ON AN INCANDESCENT LAMP

Hours Burned (Forced Voltage)	Per Cent Initial Lumens (At Normal Voltage)
0	100
50	92
110	87
170	81
230	76
266 (Burnout)	

Plotted, these data provide the performance curve shown in Fig. 1. The lumens immediately preceding burnout can be closely estimated by extending the straight line through the last two measured points as indicated by the dotted line.

The average per cent lumens throughout life in terms of initial lumens is the average ordinate of this graph and it is obvious that this can be found either by determining the mean height of the area under the curve, or by ascertaining the mean height of the area above the curve and subtracting from 100 per cent. The latter method is the one the electric calculator employs, but the process is automatic and the average percentage of initial lumens is read directly by the operator.

The theory can be more readily explained by considering the mathematics, step by step. It is obvious from Fig. 2 that the average depreciation is equal to the total shaded area divided by the total burning hours. The total area is made up of the smaller areas A_1, A_2, A_3, A_4, and A_5. The area of the triangle A_1 is the product of the base and half the altitude; the area of each of the trapezoids A_2, A_3, etc., is the product of its base and half the sum of its two end altitudes.

$$A_1 = T_1 \times \frac{D_1}{2} = 50 \times \frac{8}{2} = 200$$

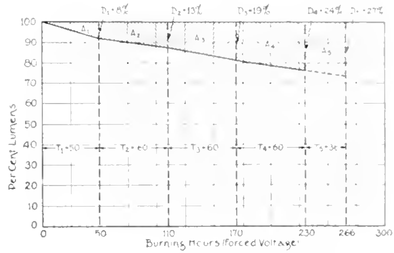


Fig. 2. Average Per Cent Lumens May be Calculated by Determining Average Depreciation and Subtracting from 100 Per Cent

$$A_2 = T_2 \times \frac{D_1 + D_2}{2} = 60 \times \frac{8+13}{2} = 630$$

Similarly,

$A_3 = 960$
$A_4 = 1290$
$A_5 = 918$
Total area $= 3998$

$$\text{Ave. depreciation} = \frac{3998}{266} = 15\%$$

Ave. percentage of initial lumens $= 100\% - 15\% = 85\%$

Consider, now, the electrical arrangement shown in Fig. 3, in which the vertical resistances are all equal and are calibrated in terms of per cent lumens as shown. The horizontal resistances are used for adjusting the current, which is measured by the ammeters A. The contacts, C_1 and C_2, roll along the vertical resistances. If now contact C_1 is set at 92 per cent lumens (8 per cent depreciation) and the current is adjusted proportionately to the first burning interval, 50 hours, the IR drop across ab will be proportional to the area A_1, 200. For, if K is a suitable constant:

$$E_1 \text{ (read on voltmeter } V_1) =$$
$$IR = T_1 \times \frac{D_1}{2} \times K = 50 \times \frac{8}{2} \times K = 200K = A_1K$$

Similarly, if contact C_2 is set at 87 per cent lumens (13 per cent depreciation) and the current in the second block is adjusted proportionately to the second burning interval

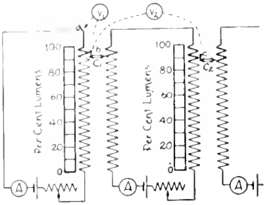


Fig. 3. Portion of Electrical Calculator

of 60 hours, the IR drop across bc will be proportional to the area A_2, 630:

$$E_2 \text{ (read on voltmeter } V_2) =$$
$$IR = T_2 \times \frac{D_1+D_2}{2} \times K = 60 \times \frac{8+13}{2} \times K$$
$$= 630K = A_2K$$

The IR drop across ac would, of course, be the sum of E_1 and E_2, and by adding a sufficient number of elements a total voltage drop proportionate to the total shaded area of Fig. 2 is obtained.

The complete device is shown in Fig. 4. The elements 4 and 5 are movable laterally so that they may be set by means of the pointers P_3, P_4, and P_5 over the "Hours Burned" scale at points corresponding to the test data. The sliding contacts C_3, C_4, and C_5 on these three elements are so connected together mechanically that they are always on a straight line; hence if the contacts on elements 3 and 4 are set to correspond with the last two readings of lumens, the contact on element 5 automatically takes a position corresponding to the extrapolated value of lumens immediately preceding burnout.

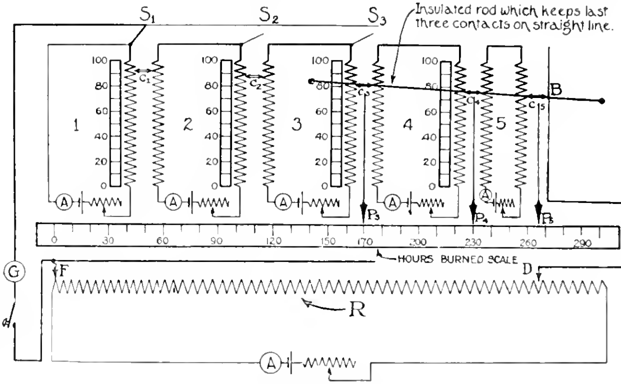


Fig. 4. Diagram of Calculator

The total IR drop from B to S_1 through the adjusted resistances, as indicated by the heavy line in Fig. 4, is proportional to the total shaded area of Fig. 2. The "Hours Burned" resistance, R, is always kept proportional to the hours the lamp has burned because the contact D is directly connected to the fifth element and moves as this element is moved. The current through the resistance R is adjusted so that the galvanometer, G, shows no deflection. When this condition obtains, the IR drop in resistance R (from F to D) is equal to that from B to S_1, and therefore is proportional to the total shaded area of Fig. 2. The total shaded area is equal to its average height times its length; therefore by correct calibration between the hour scale along resistance R and the ammeter in its circuit, the ammeter will read average per cent lumens throughout life.

The switches S_1, S_2, and S_3 merely permit elements 1 and 2 to be cut out of the circuit when the test data cover a smaller number of intervals; the "Hours Burned" scale and contact F are then moved correspondingly to the right.

Two points are to be especially noted as essential to the practical operation of the device: First, the potentiometer method of balancing the IR drops avoids the distortion of current which would result if the set-up were to be bridged with a resistance circuit, for when the galvanometer shows no deflection, no current is being taken from the main set-up and sent through the balancing resistance, R. Second, when a balance is secured, none of the rolling contacts carry current; they serve merely to add up the various voltage drops in the several elements.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Alternators—High Frequency

Production of High Frequency Current by Means of Alternators. (In French.)
Génie Civil, June 11, 1921; v. 78, pp. 507-508.
(Summary of the various methods.)

Coal, Pulverized

Pulverized Firing in Steam Generation. Crolius, F. J.
Assoc. Ir. & St. Elec. Engrs., June, 1921; v. 3, pp. 161-198.
(Hazards, methods of preparation, distribution and firing, costs, and probable applications in the future.)

Converters, Synchronous—Testing

Stray Losses in 60-Cycle Synchronous Booster Converters. Hague, F. T.
Elec. Jour., July, 1921; v. 18, pp. 292-296.
(Shows how losses may be determined by input-output tests.)

Electric Controllers

Alternating-Current Controllers Automatically Operated. Kirkgasser, G. J. and Seeger, E. W.
Elec. Rev. (Chgo.), June 25, 1921; v. 78, pp. 1011-1015.
(Types of starting and regulating devices for squirrel-cage, slip-ring and synchronous motors. Twelfth article of a series.)

Electric Current Rectifiers

Mercury Vapour Rectifiers. Some Notes on Recent Developments.
Elec. Times, June 9, 1921; v. 59, pp. 554-556.
(Illustrated account of recent large-size European apparatus.)

Electric Drive—Steel Mills

Power Generation in Steel Mills and Its Relation to Frequency. Petty, D. M.
Assoc. Ir. & St. Elec. Engrs., June, 1921; v. 3, pp. 199-212.
(Primarily from the standpoint of costs.)

Electric Furnaces

Automatic Heat-Treating Furnaces. Lacher, Gilbert L.
Iron Age, June 30, 1921; v. 107, pp. 1754-1755.
(Electric furnaces with automatic charging, quenching and drawing.)

Electric Melting Nonferrous Alloys. Gillett, H. W.
Foundry, June 15, 1921; v. 49, pp. 468-474.
(Includes a table listing all U. S. installations of electric furnaces for non-ferrous work, and another showing applicability of various furnaces for various alloys.

Mold Serves as Electric Furnace. Kreutzberg, E. C. *Iron Tr. Rev.*, July 7, 1921; v. 69 pp. 33-35.
(A novel centrifugal casting scheme for pipe, in which the mold serves as the electric furnace for melting.)

Electric Heating, Industrial

Automatic Electric Bake Oven. Strait, John M. and Woodson, J. C.
Elec. Jour., July, 1921; v. 18, pp. 296-300.
(Shows construction and operating characteristics of commercial size ovens for baking food.)

Electric Motors

Relationship Between Efficiency and Working Costs of Small Motors and Generators. Kennard, E. G.
Elec. Rev. (Lond.), June 17, 1921; v. 88, pp. 771-773.
(Includes considerable material useful for the designer. Serial.)

Electric Motors, Induction

A "Synchronous-Induction" Motor. Hoeffleur, A. (In German.)
Schweiz. Bau., July 2, 1921; v. 78, pp. 8-11.
(Illustrates and describes an Oerlikon motor having a special patented system of electrical connections. Its name is derived from the fact that it is claimed to possess advantages of both types.)

Electric Motors, Synchronous

Starting Characteristics of Synchronous Motors Shand, E. B.
Elec. Jour., July, 1921; v. 18, pp. 309-313.

Electric Transformers

Transformer Connections of Variable Voltage Ratio for Saving Winding Material. Richter, Rudolf. (In German.)
Elek. Zeit., June 9, 1921; v. 42, pp. 613-616.
(Explanation of a new system of connections for voltage control of single-phase transformers.)

Electric Transmission Lines

Factors Affecting Long-Distance Bulk-Power Transmission.
Elec. Wld., June 25, 1921; v. 77, pp. 1477-1480.
(Methods of voltage regulation of 220-kv. lines by proper distribution of synchronous condensers and of minimizing insulator destruction from flash-over.)

Gas and Oil Engines—Diesel

Diesel Engines for Generator Driving. Darling, C. S.
Beama, June, 1921; v. 8, pp. 547-553.
(Serial.)

Insulation

Insulating Materials Used in Construction and Repair of Electrical Machinery.
Elec. Rec., June, 1921; v. 29, pp. 366-369.
(Discusses the general features of various insulating compounds.)

Magnetic Properties Testing

Methods of Magnetic Testing. Spooner, Thomas.
Elec. Jour., July, 1921; v. 18, pp. 316-322.
(Theory and methods, including diagrams of connections. Serial.)

Magnetic Separation

Magnetic Separator Pulleys in Coal Plants. Costello, W. H.
Blast Fur. & St. Pt., June, 1921; v. 9, pp. 401-403.
(Cutler-Hammer engineer describes the construction of magnetic separator equipment for coal pulverizers.)

Metal Coating

Treating Metal to Resist Heat. Farr, Arthur V.
Iron Tr. Rev., June 23, 1921; v. 68, pp. 1724-1727.
(Describes method of calorizing and illustrates effect of heat tests on treated and untreated metals.)

Power Factor

Consideration of Power Factor in Reckoning Current Consumption in A. C. Installations. Paulus, C. (In German.)
Elek. und Masch., June 5, 1921; v. 39, pp. 284-286.
(Points out the error in billing consumers without taking power factor into account, and says that no satisfactory meter for accomplishing this has yet been devised.)

How to Measure Average Power Factor with Reactive-Component Meters.
Elec. Wld., June 25, 1921; v. 77, pp. 1491-1492.
(Details and diagrams of connections of two outstanding methods.)

Protective Apparatus

New and Improved Types of Apparatus for Protecting Central Station Equipment.
Elec. Rec., June, 1921; v. 29, pp. 386-394.
(Illustrated description of recent types of protective devices.)

Principal Recent Methods of Automatic Sectionalizing of Electric Circuits in Case of Excess Current. Scoumanne, D. (In French.)
Revue Gén. de l'Elec., June 11, 1921; v 9, pp. 843-851.
A discussion of various schemes. Serial.)

Rates

Analysis of Wholesale Electric Costs. Van Deventer, F. M.
Blast Fur. & St. Pt., June, 1921; v. 9, pp. 374-376.
(Presents graphic charts intended to facilitate calculation of total cost and unit rate for wholesale power users purchasing on various scales of prices. Serial.)

Reactors

Earthing Through Choke Coils as a Means of Protection Against Accidental Grounds and the Resulting Excess Voltages. Bauch, R. (In German.)
Elek. Zeit., June 2, 1921; v. 42, pp. 588-591.
(Discusses "phase-grounding" in comparison with the usual neutral-point grounding. Serial.)

Relays

Applying Relays to Large Power Systems. Gooding, R. F.
Elec. Wld., June 18, 1921; v. 77, pp. 1421-1424.
(Practical methods of selecting and installing.)

Steam Turbines

Recent Advances in Steam Turbine Design. Stoney, Gerald.
Elec'n (Lond.), June 24, 1921; v. 86, pp. 774-780.
(Illustrated paper of descriptive nature.)

NEW BOOKS

Applied Electrochemistry and Metallurgy. Burgess, Charles F., and others. 198 pp., 1920, Chicago, American Technical Society.

Berechnung Elektrischer Leitungsnetze in Theorie und Praxis. Ed. 3. Herzog, Josef, and Feldman, Clarence. 731 pp., 1921, Berlin, Julius Springer.

Electrodeposition of Copper and Its Industrial Application. Denny, Claude W. 108 pp., 1921, N. Y., Sir Isaac Pitman & Sons, Ltd.

Introduction to Technical Electricity. Starling, S. G. 181 pp., 1921, London, Macmillan & Co.

Lehrgang der Schaltungsschemata Elektrischer Starkstrom-Anlagen. Ed. 2, Vol 1. Teichmuller, J. 131 pp., 1921, Berlin, R. Oldenbourg.

Lubricating and Allied Oils. Evans, Elliott A. 128 pp., 1921, N. Y., E. P. Dutton & Co.

National Electrical Safety Code. Ed. 3. U. S. Bureau of Standards. 366 pp., 1921, Wash., Government Printing Office.

Oil Fuel. Ed. 4. Butler, Edward. 310 pp., 1921, Phila., J. B. Lippincott Co.

Personnel Relations in Industry. Simons, A. M. 341 pp., 1921, N. Y., Ronald Press Co.

Relativity, the Electron Theory and Gravitation. Ed. 2. Cunningham, E. 148 pp., 1921, N. Y., Longmans, Green & Co.

Small Motors, Transformers, Electromagnets. Stoller, H. M., and others. 320 pp., 1920, Chicago American Technical Society.

Transformatoren. Vidmar, Milan. 702 pp., 1921, Berlin, Julius Springer.

Wireless Telegraphy with Special Reference to the Quenched Spark System. Leggett, Bernard. 485 pp., 1921, N. Y., E. P. Dutton & Co.

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GENERAL ELECTRIC REVIEW

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IRRIGATING 500 ACRES OF ALFALFA ON A CALIFORNIA RANCH
Pump operated by 30-h.p. induction motor Water lift 22 feet

GENERAL ELECTRIC REVIEW

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Twenty five-horsepower Induction Motor Driving 4-in. Centrifugal Pump for the Irrigation of a California Ranch; Water Lift About 45 Feet
Irrigation is absolutely necessary to the tilling of the soil in many portions of our middle and western states
and electric power is pre-eminent for this work

GENERAL ELECTRIC REVIEW

IRRIGATION

It has been said that there is no greater benefactor to mankind than he who causes two blades of grass to grow where only one has grown before. This is a self-evident truth and it takes little force of logic to show that those who cause abundant crops to grow in waste places are real benefactors to their country and to the world at large.

Mr. K. A. Hills in his article published in this issue shows how the electric motor is serving mankind in irrigation projects. We have often pointed out in these columns how during the last quarter of a century the electric motor has become one of the greatest factors in our modern industrial life and how today it must be recognized as one of the most useful agents in building up our twentieth century civilization.

The wealth, prosperity and happiness of nations depend largely on what the soil produces. Crops are literally wealth produced; and the surplus that any nation can produce for export to foreign countries must always be a measure of its trade balance with the outside world. In a measure the same is true of the mining of metals and minerals, with the great difference that a mine finally yields up its full treasure, while the soil, if water and fertilizer are applied, brings forth its increase from one generation to another. In fact, some of the land in Europe and Asia that has been yielding crops for centuries is still coaxed to bring forth crops equal to any.

It should be no small satisfaction to the electrical engineer to realize the untold field that lies before him, as yet barely entered, for applying his genius to irrigation and to the production of artificial fertilizers. Nature has played so fully into his hands that the electrical engineer must be the presiding genius in practically all large schemes for reclaiming the desert.

If a river has to be dammed to conserve the water for irrigation purposes the electrical engineer makes use of the enslaved waters to generate electric energy and makes the mighty waters pay a double tribute to mankind—first to furnish power for a multitude of purposes, and after he has robbed it of its potential energy he uses it to raise the crops. If the lay of the land is such that gravity cannot be persuaded to bring the water to the farm, then a distant waterfall is used to generate electric energy and electric pumps are used to bring the water to the land.

Pierpont Morgan once said that the man who went "bear" on America would some day become a bankrupt he might with equal truth have said the same thing concerning the electrical industry, as although we are going through a period of depression just at present the future of the industry seems to be too limitless for the imagination of man even to dream of its scope.

At present irrigation is but a small part of our business, but what of the future? In the East there are innumerable instances of artificial irrigation to supplement our rainfall and insure crops, in spite of the uncertainty of weather conditions, and in such regions and climates the engineer will find an ever increasing demand for his skill in helping the farmer, but when we think of the real future of irrigation our minds naturally turn to America's great heritage in the West beyond the Mississippi.

Mr. Hills shows in his article that in 1909 there were 1,679,084 acres of land under irrigation in the state of Montana alone and that by 1920 this figure had increased to 2,136,974 acres. He also shows that the area capable of being developed by irrigation in Montana is 5,288,517 acres. These figures are only for one state and if we include all the other states in the West the figures would be truly enormous. Some of the prairie lands have already been turned into fruitful farms and some of the desert has been reclaimed, but how many acres of thirsty, barren desert are still waiting for the engineer?

Under natural conditions, taking the lean years with the fat, farmers may or may not make a living. With irrigation the production of crops becomes more like a manufacturing business and certainty takes the place of uncertainty.

Electrical Aspects of the Pueblo Floods

By A. L. Jones

Engineer, Denver Office, General Electric Company

The author of this article was one of those who went from Denver to Pueblo to help restore electrical service in the stricken city. He describes the manner of drying out the turbine generators, motors, transformers, instruments, etc. His description should be of value to anyone called on to assist in similar work in the future.—Editor.

The Pueblo flood was probably the worst disaster of its kind in the memory of the present generation. A large section of Colorado's second city was overwhelmed and unbelievable and indescribable damage done. A city suddenly without light, gas, telephone, water supply or street cars—separated into three parts by raging torrents and cut off from all communication with the outside world—such was Pueblo on the eventful Saturday morning of June 4th.

The Arkansas River, which did most of the damage, flows through the city in a generally southeasterly direction, crossing the lower business district in a walled channel; the surrounding country above and below the town is protected by levees rip-rapped with smelter slag. The watershed of the river is very precipitous and practically devoid of forests. Violent storms and sudden rises of the river are frequent late in May and early in June. The river channel through the city has a capacity of three or four times the average flow and the channel has in the past proved adequate for flood waters.

The flood of Friday, June 3rd, was caused by a series of cloud bursts about twenty miles above Pueblo. Flood waters reached the city about 5:30 p.m. and by 8:00 p.m. had reached the bridges and begun to overflow the city. About 8:30 the fires in the plant of the Arkansas Valley Railway Light & Power Company were put out and the city was in darkness, save for the frequent blinding flashes of lightning. The debris which collected on the bridges diverted the steadily rising waters into the streets. In finding an outlet the waters tore through blocks of one and two-story buildings in the poorer business district, and through the freight yards of the Denver & Rio Grande Railroad, wrecking over four hundred freight cars.

The damage to the upper and better business district, which lies seven or eight blocks north of the river, was from another cause; the river as it passed through the town should have done little more than flood this district with back water, but actually the severest damage was in the very heart of the commercial district. About a mile above the center of the city the river makes a sharp turn to the south. This turn is heavily protected by levees. The rapidly rising water overflowed and undermined the levee at the turn and permitted a torrent to cross the business district to join the river lower down. Behind this levee lay the "Peppersauce Bottoms," a thickly built up section of small frame houses. Terrible havoc was wrought here and a heavy toll of lives taken. Then the torrent crossed the freight yards of the Atchison, Topeka & Santa Fe Railroad, demolishing structures and washing cars from the track. The combined wreckage of houses, freight cars, lumber, etc., was hurled into and through the business district and terrible destruction of property was caused by the irresistible impact of floating material and the fearful velocity of the current.

The crest of the flood was reached about midnight, when the water stood from nine to twelve feet deep in the various buildings. The flood of the Fountain River, which joins the Arkansas in the eastern part of the town, came on Sunday, and while it was quite disastrous to bridges, railway tracks and structures along its banks, it did not overflow the city proper. The extra water, however, delayed the draining of the flood water from the city. By Sunday morning the flood had receded and the work of cleaning up started.

The big steel works of the Colorado Fuel & Iron Company is located at the south of the city on high ground and was untouched by the flood. The steel works has its own power plant and water works. These were placed at the service of the city. A short power line was built on Saturday afternoon and Sunday, connecting the lines of the two companies, and on Sunday night a considerable portion of the residence district had lights and during the next few days all the undamaged parts of the city were lighted, the essential power also being supplied from the steel works. The water works on the south side of the city was put out of commission by the flood, but in a day or two the steel works tapped the city mains and supplied water for the south side of the city.

On Saturday afternoon the Arkansas Valley Railway Light & Power Company began cleaning out its power house, which stood in the very center of the flooded district. The water in receding had left a deposit of fine silt from one to three feet deep over everything. At first it looked as if the men were merely wading, slushing and splashing mud and water and making no appreciable progress. The force at the power plant, car barns, shops and yards numbered nearly 300. The Company established a commissary in the power house and served free meals, not only to its own force, but to anyone else who appeared. Many of the men had lost their homes and slept in the building.

Partial telegraphic service was re-established on Sunday afternoon and some idea of the extent of the disaster reached the outside world. The large power companies of the state wired offers of assistance. On Tuesday the first rescue train reached the outskirts of the city. This train was restricted to relief material, doctors, nurses and military forces for police duty. On Wednesday a train reached the partially excavated Union Depot. This train carried quantities of telephone material, pumps, etc. Three members of the Denver office of the General Electric Company, armed with special permit from the Governor, and loaded down with filter paper, meggers, meters, thermometers, etc., were on this train to offer their assistance to the power company in drying out the generating equipment. It proved to be no white collar job and the experience that the G-E men had gained in the Testing Department proved to be invaluable.

Another member of the Denver office made his headquarters at Colorado Springs, which was the only gateway open to the stricken city. The military forces had established a dead line here, stopping all persons and side-tracking material not absolutely essential to flood relief. The G-E representative secured the necessary permits and with the co-operation of the Colorado Springs Light, Heat & Power Company reloaded the material and saw to the prompt forwarding. Such material as filter papers, oil testers, transformer oil, etc., were forwarded immediately, G-E men frequently riding through with the shipment to prevent any delay.

The plant of the Arkansas Valley Railway Light & Power Company is on the river bank and at this point the water reached a depth of eleven feet above the surrounding property. The boiler room is on the ground level while the engine room is approximately six feet higher. Water stood approximately eleven feet deep in the boiler room and about five feet deep in the engine room. The generating equipment consists of:

- Unit No. 1 960-kw., 2300-volt G-E engine type alternator
- Unit No. 2 650-kw., 2300-volt G-E engine type alternaor
- Unit No. 3—800-kw., 575-volt G-E d-c. engine type alternator
- Unit No. 4—1500-kw., Allis Chalmers 30-cycle turbine generator
- Unit No. 5—1500-kw., Allis Chalmers 60-cycle turbine generator
- Unit No. 6—2000-kw., 60/30-cycle G-E frequency changer set, 2 turbine generator exciter sets
- Arc tubes, etc.

The damage to the boiler room was nominal. Fires were drawn just as the water reached the bottom of the chain grate stokers. The sudden cooling of the settings and the submerging seems to have done little or no damage. The outside of the boiler settings was covered with a tar and asbestos compound to reduce air leakage and this evidently prevented absorption of water by the bricks. Inside the settings the glaze did not permit water to be absorbed. As fast as the mud could be cleaned out the boilers were fired, and no trouble has been experienced with the settings. The ash conveyor tunnel was filled solid with mud and it proved to be a big job to get the ash conveyors working.

The power plant building, car barns, shops, etc., were not damaged by the torrent, being protected considerably by the new power plant which the company is building at the back of the present structure. Neither the foundations of buildings nor of machinery were injured.

The turbines and engines operate condensing, the condensers being installed in a pit which was completely filled with mud, and it took over a week of steady work to clean it out and overhaul the various vacuum pumps, feed pumps, oil filters, etc.

The work of cleaning out the power house began on Saturday and by Tuesday night the mud was all out of the engine room and everything had been washed down with a fire hose to remove the mud and slime. One boiler had been dug out, a temporary feed pump installed, and the boiler was under steam. A geared

Fig. 1. Fourth Street Bridge for Street Cars and Wagons. Only bridge left out of six. Foot bridge shown made from street car rails and ties

Fig. 2. Arkansas Valley Railway Light and Power Company's New Power Plant Under Construction

Fig. 3. North Union Avenue

Fig. 4. Denver and Rio Grande Railway Yards from C Street Viaduct

turbine exciter had been dismantled, the bearings and gears washed out, and was run all Tuesday night to fan it as dry as possible.

A large engine-driven 575-volt direct-current generator for the railway seemed the most difficult problem. The bearings and oiling system of its cross compound engine were dismantled and cleaned. The engine was turned over and the generator put on short circuit Thursday, June 9, separately exciting it from the geared turbine exciter, having first disconnected the series field. The fields of the various alternators were connected to the exciter as fast as the wiring could be arranged. It was decided next that the short circuit current of the railway generator might as well do some further work in drying out the machinery, so it was passed through the stationary armatures of the rotary converters, turbine alternators, motor generator sets, and engine type alternators. The current to each piece of apparatus was known, as the d-c. generator had been connected between the bus and ground, and the machines being dried were connected to the various d-c. feeder circuits, and the ammeters indicated the current in each machine. The distribution of current could not be controlled, being determined by the resistance of the circuit. If the current to any piece of apparatus was too high, it was operated intermittently, keeping the temperature of the winding to a safe value. This method was a temporary expedient to accomplish all the drying possible pending the time the various generators could be run and placed on a short circuit. This procedure, however, had to wait until more boilers could be prepared for service and the engines cleaned, etc.

On Friday, June 10th, the generator of No. 1 engine, a 960-kw., 120-r.p.m. engine type alternator, was ready to turn over, and was put on short circuit. Full load current was sufficient to warm the coils and laminations. The speed of the engine was held low as it did not affect the value of the short-circuit current, and as the engine bearings, brasses, etc., had been assembled with plenty of play it was not advisable to operate at high speed. As the drying out progressed the various bearings were keyed up and the speed raised, until by the time the drying was completed, the engine ran smoothly and with cool bearings. Megger readings were taken from time to time as the drying progressed. The seemingly long time required to get any indication of insulation resistance was discouraging. This 960-kw. generator ran short circuited for about 96 hours before the megger showed any resistance. The revolving field even up to the time the drying was completed showed no insulation by the megger, but as it had carried current for days during the drying out, it seemed safe to operate it and such proved to be the case. The megger reading on June 14th was 25 megohms, 10 megohms on the 15th, and 50 megohms on June 17th. The machine was regarded as ready for voltage. It was, however, used for drying out transformers and other station equipment and was not put under full voltage until June 23d.

No. 2 generator, a 650-kw. engine type machine, was short circuited about 100 hours before it showed appreciable insulation resistance. The field never responded to the megger test, but the entire unit operated satisfactorily when put on the line.

The 800-kw., 600-volt direct-current railway generator proved the most difficult task. This unit was put under short circuit on June 9th, and the current gradually increased to 2000 amperes. This current was used for drying out other machines, such as rotary converters, frequency changer sets, etc., which could not be conveniently driven, to dry out under short circuit. This current was sufficient to keep the armature windings and laminations quite warm, but even after a week of continuous operation the megger showed zero resistance. Measurements were then taken by a high resistance direct-current voltmeter with the following results:

June 17— 900 ohms
June 20— 2200 ohms
June 21—1600 ohms

Such progress was slow and discouraging. The windings appeared to be well dried out and it was decided that the trouble must be under the commutator. To better ventilate this part every other bolt in the outer clamping ring was removed and it was found that the space under the ring was filled with felt which was wet. Torches were applied to the underside of the commutator, with an asbestos barrier at the back to keep the flame from overheating the armature proper. The temperature of the commutator was raised to 110 or 115 deg. C., while the machine was revolving slowly. The torches were removed and the machine shut down twice daily to check the temperatures and take resistance measurements. After three days of this treatment it was disappointing to find little gain in insulation resistance, even though there was every indication that the felt was dry. It was finally reasoned that the failure to respond to the megger must be due to the presence of dirt which was grounding the commutator. Wire brushes were brought into action and the armature and commutator were given a thorough cleaning, especially the back, or inner clamping ring of the commutator. The results of this cleaning were immediately apparent as a megger reading of 1500 megohms was obtained. No particular efforts were made to dry out the series field, as it was on the ground side of the armature. On June 29th the machine was operated at 620 volts for two hours and was passed as ready for load. The armature was given a coat of paint before the machine was put on the line on July 4th. Partial railway service had been established on June 27th through a rotary converter.

The 1500-kw. turbine units, Nos. 4 and 5, were dried out by direct current from the railway generator while the turbines were being prepared for service. The turbine bearings and oiling systems had to be dismantled and washed out. After some days of operation, during the short circuit run, the turbines began to vibrate excessively and an investigation showed that the blades had filled up with mud, which evidently came over with the steam. During early operations the engines and turbines were operated non-condensing as the condensing equipment was not ready to operate, and the boilers were fed with exceedingly dirty river water. Some of the dirt lodged in the turbine blades. On June 14th, when No. 4 unit was placed on short circuit, the armature resistance was .2 meghom. On June 17th the reading was .28 megohm and on June 27th, 800 megohms. The field measured zero with the megger at all times, but was put in regular operation without difficulty. The No. 5 unit showed an insulation resistance of 200 megohms on June 17th, and after cleaning the blades it was put in commission on June 25th.

The cables between the generators and switchboard were in iron conduits and the low points of these conduits were drilled to draw off any trapped water and, where possible, the short circuit was put on the machine at the switchboard, which dried the cables as well as the generators.

The oil switches on the switchboard, the watthour meters, relays, rheostats, etc., were submerged, but most of the instruments escaped, as the water rose to just below the lower row of instruments. All the oil switch tanks with their wooden linings were dried out in an oven erected at the back of the boilers, braces first being placed in them to prevent bulging of the lining. Relays were dried in the oven, the only difficulty being that the fiber supports which carry the contacts tended to swell during the drying to two or three times their former size. This was overcome by placing strips of wood above and below the fiber and holding it tightly with clamps during the drying. The Thompson direct-current watthour meters mounted on the sub-base of the board suffered surprisingly little damage. The close-fitting glass covers with felt gaskets prevented water from entering and none were hurt in the least.

In the basement under the engine room were the busbars, disconnecting switches, solenoid operated oil switches, etc., also the constant current transformers. This basement had been filled with mud and nearly two weeks elapsed before it could be cleaned out. Potential and current transformers were taken down and dried in an oven. The marble bases of disconnecting switches showed practically no insulation when tested with the megger. It was decided to try to dry this basement "en masse." Steam pipes were placed through the basement, a good current of air was circulated and a high temperature was maintained for several days; and judging from the operation since, this process was a success. A few potential transformers failed later, but they were all of old design and of doubtful insulation.

The transformer room has its floor about three feet below the street level and the water rose sufficiently to completely submerge the transformers, even to the top of the high tension bushings. There were twelve 500-kw. transformers in this room. After cleaning out nearly four feet of mud the oil valves were opened and the free water drawn off. The quantity of water varied from a bucket to nearly the capacity of the transformers. The smallest quantity came from a bank of 60,000-volt outdoor type transformers, with their tightly fitting covers, while three old style indoor type transformers in low square tanks had lost nearly all their oil and were found to contain nearly a foot of mud in the bottom of the tanks. The remaining two banks, while not of outdoor construction, had relatively tight fitting covers and had not taken in more than a barrel of water each.

The primaries and secondaries of the transformers were meggered and with the exception of the three mentioned showed good insulation. Feeling that the oil was wet from leakage of water, and that the water had undoubtedly lodged in the windings, it was decided to filter the oil. This was done and water was found to be so plentiful that filter papers at first would be absolutely saturated and limp in five or ten minutes. After twenty-four hours' filtering the oil began to show up satisfactorily when tested with a standard gap. The three secondaries were then short circuited and sufficient three-phase voltage supplied to circulate full load current. As the transformers heated up, moisture was driven off and the oil became very wet again. Filtering was continued until no more moisture could be caught on the filter papers and the oil stood a test of 22,000 volts across the 1/10-in. gap and megger reading of 700-1000 megohms were obtained in the primary.

During the early stages of filtering the filter papers had to be changed much faster than the ovens could dry them out. To speed up, a system of checking the progress of drying papers was devised, using the megger. A sample paper was placed between two metal plates about 4 in. square and the reading of the megger gave sure indications of how far drying had progressed. Where papers had previously been left nearly four hours, they were taken out of the oven in one-half to three-quarters of an hour, and in this way the work was much expedited. Nine transformers were dried by simply filtering the oil and heating up the transformers, and these nine transformers went on the line without failure. Two of the transformers were found to have been burned out when water entered them, being excited at the time from the transmission line to another plant.

The meter department of the company began as promptly as possible to collect all the meters that had been submerged. Over 1000 meters were brought in, with still about 200 more unaccounted for. Most of these were in the houses that had been completely demolished by the flood. The meters were thoroughly washed by spraying with water until every particle of dirt had disappeared. They were then dipped in a bath of kerosene, not wetting the coils more than could be helped. Next they were placed in an oven and baked for from eight to twelve hours, after which the insulation was tested by use of a megger. After a time, however, it was found that a man with damp fingers could detect any leakage through the coils of the meter by placing 125 volts on the winding and placing himself in circuit. If on touching the outside of the coil he could not feel any leakage the meter was passed as being dry. This method of testing was checked up from time to time with the megger and was found to give satisfactory results. After drying, any surplus oil was wiped off, the jewel and pivot inspected and replaced if worn sufficiently to require it. Usually the disc and magnets were removed and cleaned and the register mechanism oiled with clock oil. The meter was then assembled and calibrated. A rack was devised to hold eight meters and they were calibrated eight at a time. A man could handle five racks, or 40 meters a day. No difficulty was found in securing practically 100 per cent accuracy on these meters, and the ones which were reached promptly after the flood hardly showed a mark to indicate that they had been submerged. Meters of all makes and ages were brought in. General Electric meters, especially I-14 and D-6, developed no weak points whatever and were apparently in every respect as good as before the flood. Certain other makes of meters did not come out quite so well; the registers having steel shafts rusted; the steel thrust plates under the various vertical shafts had rusted and the shafts and plates had to be renewed. The fiber in these meters also warped badly. Some few meters were injured mechanically but these were about the only ones that were not put back into service.

The distributing lines were disturbed for a radius of six to eight blocks from the plant. The main circuits were not badly disturbed beyond the breaking of guys, poles bent over, etc. Most of the expense was for labor in straightening the pole lines, taking up slack, etc. About 25 ornamental lighting standards were knocked down, but only certain parts were broken and probably 80 per cent of the material will be reclaimed. Throughout the business district the poles carrying the trolley span wires were tubular steel. Some 51 of these were damaged, being bent over or broken off. Usually only the lower section was injured and new parts will be supplied and the poles reset. In the flooded district there were about two miles of double trolley wire. This was all recovered excepting about three quarters of a mile.

A number of transformer stations were in the basements of business blocks, and some transformers were thrown into the mire by the breaking of their supporting poles. Some of these transformers were in the water from one to two weeks. They were washed off with a hose as soon as recovered and dried by short circuit current; 24 to 48 hours were required to show satisfactory megger readings. These transformers were all put back in service without loss.

The wiring in the buildings was mostly in conduit and this conduit on the lower floors was filled with water. Most of these circuits tested so low that the wires were pulled out, rags drawn through and then new wires pulled in.

The street cars suffered less than any other department. They were all ordered to higher parts of the city when the water began to rise. Only four were caught by the flood waters. The motors of these can be dried out and they will soon be in service again. Street car service started on June 27th, though the flood district was still too blocked with debris to permit cars to cross the down-town section, so service started as shuttle lines radiating out of the business district. Normal service was established on July 4th.

Looking through the haze of first impressions of the flooded plant, to the restored and operating property, one is struck by the greatness of the transformation and how insignificant was the damage to the equipment. The success of the electrical machinery of all kinds in besting its traditional enemy, water, is a high tribute to the progress of the art.

The spirit of the power company's organization in turning its hand to anything and everything which would speed the rehabilitation was an inspiring thing. The dominant impulse was to give the public full electrical service at the earliest possible moment. The public in turn seemed to realize, in a way, the great obstacles to be overcome and were very patient and appreciative as service approached normal.

Pueblo is far from discouraged by the disaster, and reconstruction of every kind is going on at a surprising rate, and all replacements are of a better grade of construction than the original.

Fig. 5. Street Cars Caught by the Flood

Irrigation in Montana with Electrically Operated Pumping Plants

By K. A. Hills

Butte Office, General Electric Company

The importance of irrigation needs no emphasis. The author shows what the state of Montana is doing in this direction and how much there is still left to be done. This article should be of special interest to the electrical engineer as well as to the rancher as its purpose is to show what an important part electrically driven pumps can play in the scheme of turning the waste lands into gardens and farms.—Editor.

The abnormally dry conditions in practically all sections of Montana for the past three years have caused crop producers to study how irrigation might be applied to insure crops. As one writer has expressed it: "Wherever one finds the most valuable crops, the highest priced plant and the most prosperity, there he finds irrigation. With irrigation the element of chance is eliminated. Under the clouds, farming is a lottery. The questions are always: 'Will it rain?' 'Will it rain enough?' 'Will it rain at the right time?' All these problems are settled with moisture at convenience and when wanted."

The rainfall in Montana, as a general rule, averages from 12 to 15 inches; however, it has varied from year to year, from less than half to nearly twice the average quantity. It is this uncertainty that makes farming without irrigation more or less a gamble.

The early records of Old Fort Shaw show a total rainfall of 4.24 inches in 1874, and 5.67 inches in 1875; while in 1876 there was 7.2 inches in the month of May alone, and for the year a total of 14.62 inches.

There are very few sections of the state where rainfall is so plentiful that it would not pay to irrigate every acre to which water can be brought at a reasonable cost.

Data, compiled by the Montana Irrigation Commission in a report dated December, 1920, show that Montana contains 93,000,000 acres of land of which two thirds are classified as forests and grazing and the other one third as agricultural land. Table I shows the results of an irrigation survey made in 1909 by the Montana Agricultural College Experiment Station (Bulletin No. 103) and also the results of the irrigation survey of the Commission made in 1920. The figures show the acreage of land actually under irrigation.

TABLE I

	1909	1920
Irrigation districts	412	51,698
Other enterprises	1,587,530	1,839,576
U.S.R.S. and Indian Service	81,494	145,000
Carey Act projects	9,648	100,700
Total	1,679,084	2,136,974

As a result of this survey by the Commission, the additional area that can be irrigated by works being constructed or by works constructed but not in use, and by irrigation districts or private or corporate enterprises organized for beginning construction are as follows:

	Acres
Irrigation districts under the court	375,747
Irrigation districts under the commission	122,136
Other enterprises	103,360
U.S.R.S. and Indian Service	199,000
Carey Act projects	85,300
Total	885,543

The survey shows that 2,266,000 acres, not included in any of the above figures, are still susceptible of irrigation.

Following is a summary of the ultimate irrigation development in the state under the present market conditions, population, land values and duty and use of water:

	Acres
Area now being irrigated	2,136,974
Works already contemplated or districts organized	885,543
Additional area that can be irrigated	2,266,000
Total	5,288,517

Montana's main drainage system consists of the Yellowstone, Missouri and Clarke Fork of the Columbia Rivers. The above, with their tributaries, drain all of the state except a small part in the northwestern portion, which is drained by the Kootenai and St. Mary's Rivers. The Yellowstone River, whose source is Yellowstone Lake in Yellowstone National Park, drains the southeastern part of the state. The Big Horn River, which rises in Wyoming, is its largest tributary emptying into the Yellowstone River about 55 miles east of Billings.

The Missouri River has its source at Three Forks, being formed by the union of the Madison, Gallatin and Jefferson Rivers at this point. The Clarke Fork of the Columbia is formed by the union of the Missoula, Bitterroot and Flathead Rivers.

Practically all of the streams in the state have their sources in the mountains where the snowfall is heavy. Their high water flow generally occurs in June, due to the melting snows, and a high rate of flow is usually maintained through July.

Throughout the state there are extensive tracts of land which can be irrigated easily at a low cost per acre, by raising water to a higher level by using electrically operated pumps. As a rule, when an irrigation scheme revolves itself into a pumping project, the layman is of the opinion that it is not feasible; while, as a matter of fact, there are projects depending on long main line gravity canals (which are exceedingly expensive to build and maintain) in order to secure a gravity system, where a pumping system could be installed at a normal cost per acre, and could eliminate the long, expensive main line canal entirely.

The advancement in mechanical methods of irrigating land, not accessible from gravity ditches except at excessive cost, has kept pace with the needs of the irrigator, so that today it has been fully demonstrated that irrigation by electrical pumping units is both practical and economical.

There are many factors which should govern the proper selection of a pumping plant; the chief factors are:

Source of water supply
Capacity of plant
Kind of pump
Source of power
Cost of operation
First cost.

The usual source of water supply found in the state is a surface water supply, such as rivers, lakes, canals, etc. Where a surface water supply is available the water can be readily developed by means of a proper intake, which, in the simplest form, consists of the suction pipe from the pump extending into the water.

In case surface water is not available, it may be practical to develop a well which can be dug, drilled, or bored.

The required capacity of the plant depends upon the number of acres to be irrigated, the duty of water required, and the period of operation. As a rule, it will be found that one second-foot of water for each 66 acres will be sufficient. This pertains particularly to crops such as cereal grains and alfalfa. From this figure the proper capacity of the pump can be readily obtained if the number of acres to be irrigated is known.

When the proper capacity of the pump is settled the horse power of the prime mover can readily be determined if the efficiency of the pump, the total lift, and pipe friction are known.

There are several formulas that may be used to calculate the horse power required to raise the water to a given height; the following is a simple one:

$$HP = \frac{GPM \times 8.33 \times H}{33000 \times E} \text{ or } \frac{GPM \times H}{3960 \times E}$$

where

HP = Brake horse power of prime mover required by pump
GPM = Capacity of pump in gallons per minute
8.33 = Weight of one gallon of pure water
H = Total pumping head in feet
E = Efficiency of pump expressed as a decimal.

As a short cut calculation in arriving at the amount of electrical power required to raise water, it can be remembered that it requires 1.025 kw-hr. to raise an acre foot of water one foot high, based on 100 per cent efficiency.

By the term "Duty of Water" is meant the amount of water used or necessary to mature a certain acreage of crop. It may be expressed in various terms, but the most satisfactory way is to express it by the depth to which the water applied would cover the land if uniformly distributed over the surface. The unit therefore used is the acre foot, or the amount of water necessary to cover one acre to a depth of one foot. No exact rule can be laid down for any particular crop since the amount varies with the texture of the soil, sub-surface moisture, temperature, wind velocity, rate of application of the water, the irrigator and so on.

The economical duty of pumped water is necessarily higher than that of gravity water. It seems probable that, with care, to mature crops during a normal year in Montana from 1½ acre-ft. to 2½ acre-ft. of water per acre, delivered to the land, may be sufficient. A fair general average for practical consideration is 2 acre-ft. per acre per season, and allowing for losses in ditches this amount is conservative.

In this connection it must be remembered that the growing season in Montana is not long and irrigation should be stopped early enough in the fall to allow the crops to mature before frost arrives. If the land is not well prepared or if the soil is very sandy, or the irrigator is not careful, the water required to mature the crop may be much more than that mentioned. New land requires

Fig. 1 Exterior View South Station, Prickley Pear Irrigation Project, Helena, Montana

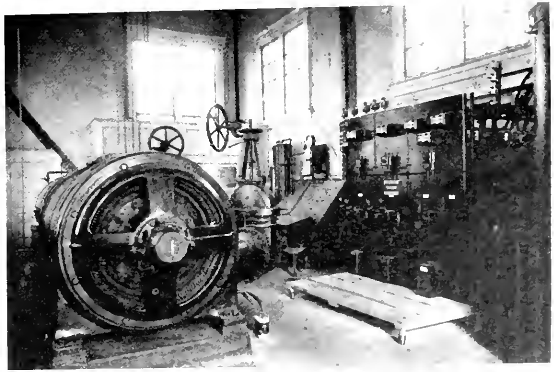


Fig. 2. Interior View South Station, Prickley Pear Irrigation Project. Two 94 [illegible] 900-r.p.m., 2200 volt, 3-phase, 60 cycle, squirrel-cage motors each [illegible] connected to a 45-second-foot centrifugal pump

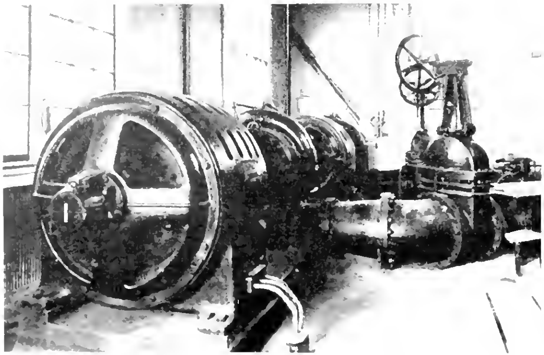


Fig 3 Interior View of South Station Prickley Pear Irrigation Project

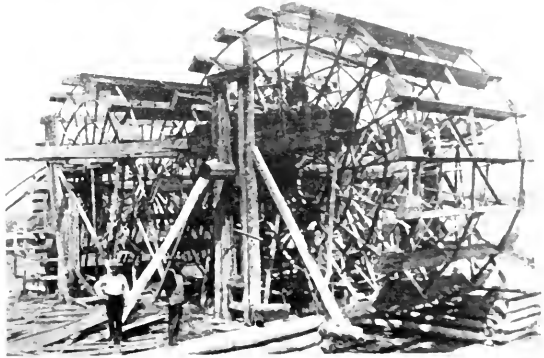


Fig. 4. Waterwheel Formerly Installed on Missouri River, Ft Benton, Montana on the O'Hanlon Land and Stock Company's Ranch

considerably more water than old land, because it is first necessary to introduce sufficient moisture for plant life, and a new crop often has shorter roots. In view of this, a larger pumping installation would be required the first year than would be required for subsequent years if it was intended to irrigate the entire acreage at first. As a rule, this will not be the case, as grading, ditching and planting the first crop will require an amount of time and labor such that it would probably be impossible the first year to place much more than half the tract under cultivation; the remaining being cultivated during the following year, which will not generally overtax the pumping equipment. Water must be applied at such intervals as the crops require, each usually requiring water at a time peculiar to its needs. For instance, winter wheat, spring wheat, oats, barley and other cereal grains require, as a rule, about a maximum of 12 inches of water during June and July, or during the time the heads are filling out. Alfalfa requires a large amount of water directly following the cutting of each crop. Sugar beets and potatoes require a maximum of about 12 inches during August and September, which is the time they are filling most rapidly below the surface of the ground. It is to be understood that the above mentioned crops require irrigating at other periods, but the above gives the maximum conditions.

Regarding the demand of water for the different months of the growing season, according to records kept by the United States Reclamation Service on the Huntley Project, for a period extending from 1912 to and including 1918, the average demand for water per month, is:

	Per Cent
May	5.4
June	18.5
July	36.7
August	32.5
September	6.9
	100.0

The average water demand will, of course, vary with the climatic and soil conditions in different parts of the state, also with the crop to be raised.

The United States Reclamation Service has operated a number of irrigation projects in Montana for several years and they have kept records of the duty of water. The data in Table II are taken from the annual report of the United States Reclamation Service.

From the foregoing data it will be seen that crops can be successfully grown by the application of a little over 1 acre-ft. of water per acre applied on the land. It is the understanding, however, that an irrigation plant will have to supply, in addition to this amount, an amount to cover the losses in the main canals, supply laterals, etc., which occur through seepage and evaporation.

In the majority of cases the centrifugal pump will be found most suitable for irrigation purposes. The extensive and growing use of electric power has doubtless been a leading factor in promoting the development of centrifugal pumps as they may be designed to operate at standard motor speeds, and to be direct connected to motors on a common base plate. These sets make ideal units free from belts or gears, with their attending noise, wear and tear. Owing to the large capacity and good efficiency of the centrifugal pump against medium heads, it is exceptionally well adapted for irrigation work.

Centrifugal pumps can be divided into two general classes, namely, the inclosed impeller type and the open impeller type, depending on the style of impeller used. For irrigation work where high efficiency is essential, the inclosed type is most generally used. Here the impellers are of the inclosed type, consisting of a number of blades or vanes of suitable curvature, radiating from a hub and inclosed by two disks or walls. The liquid to be pumped enters at the center of the impeller around the shaft on both sides, in double suction pumps, and passes through the wheel in channels formed by the walls and vanes. Double suction impellers are preferable for irrigation work as the suction is equalized on both sides, preventing end thrust. Open impeller pumps are usually installed in irrigation work where the heads are very low and the capacities very large.

The open impeller consists of a number of vanes of suitable curvature radiating about a hub, but without side walls or disks. Here the clearance between the vanes and casing is usually very small to prevent as much slippage as possible. They can not be made of as high an efficiency as inclosed impellers, owing to this excessive leakage or slippage. Open impeller pumps are less expensive than the inclosed type.

In operation centrifugal pumps are peculiar in that the head, capacity and speed all bear a direct relation to one another. A change in one will necessarily mean a change in the other two. If, for instance, a pump is designed to pump 760 gallons per minute against a total head of 49 ft., and the efficiency guaranteed is 70 per cent, while operating at a speed of 1150 revolutions per minute, the brake horse power required would be approximately 13½. After the pump is installed it may be found that the total head is but 15 ft. The capacity with this head would be 880 gallons per minute, and the efficiency 68 per cent, and the brake horse power 14.7, at a speed of 1150 revolutions per minute. While the variation is small in this particular case, the loss in efficiency will be greater when the error in ascertaining the head is greater. It will, therefore, be seen that the pump should be designed for the particular installation. Stock sizes will be cheaper in first cost, but this difference will soon vanish through the smaller power bill if it is not entirely overcome by the use of the smaller size motor, which could then be used.

The failure to appreciate the characteristics of centrifugal pumps fully has put them at a disadvantage and sometimes caused them to appear unsuitable. The fundamental characteristics of a centrifugal pump are as follows:

The capacity of centrifugal pump varies directly as the speed
The head varies as the square of the speed
The brake horse power varies as the cube of the speed.

While centrifugal pumps will lift water approximately 26 ft. at sea level, in actual practice this maximum is never reached. The maximum allowable suction lift recommended by manufacturers is 20 ft. at sea level; this includes pipe friction losses, entrance losses, etc. This suction diminishes as the altitude increases. The suction pipe on the pump should be as short as possible, and it must be air tight. A centrifugal pump can not lift water by suction unless its casing is first filled with water, for this reason it is necessary to install some means of priming. This can be accomplished by the installation of a check valve in the discharge line, and a small suction pump connected to the top of the pump casing to exhaust the air, and draw the water up through the suction pipe, or by the installation of a foot valve in the suction pipe.

The older forms of pumping which relied on wind mills and water wheels, or on internal combustion engines or steam engines have largely been superseded by the modern electric motor. In practically any part of the state electric power can be obtained at a nominal cost, as the state is well traversed by transmission lines. The Montana Power Company alone has approximately 775 miles of 100,000-volt, 3-phase, 60-cycle, transmission lines, and approximately 1150 miles of 50,000, 60,000 or 70,000-volt, 3-phase, 60-cycle transmission lines.

Electric power has marked advantages over any other form of power for irrigation, owing to the simplicity of alternating-current motors which required practically no attention. If necessary, with electrically operated pumps, they may be operated continuously for several days at a time; the only inspection required is to see that the unit is receiving sufficient lubrication. This continuous operating feature is of marked importance to an irrigator when he wishes to cover a certain acreage in the shortest space of time, as no time is lost in waiting for main canals, etc., to fill with water before irrigation is started.

The standard control equipment for alternating-current motors is provided with an attachment which will automatically disconnect the motor from the source of power in case a dangerous overload is imposed on

TABLE II

DUTY OF WATER AT THE FARM IN ACRE FEET

	1912	1913	1914	1915	1916	1917	1918	Average
Huntley	1.50	1.53	1.43	0.97	1.12	1.11	1.06	1.25
Milk River	....	0.92	0.80	0.69	0.67	1.01	1.07	0.89
Sun River	1.71	1.5	1.73	1.10	1.22	1.36	0.94	1.37
Blackfeet				1.83	0.83	1.08		1.25
Total								4.70
Average								1.20

the motor, also with an attachment to disconnect the motor automatically from the source of power in case the source of power fails. A bell alarm attachment for the starting equipment is also frequently used to notify the rancher whenever the motor is disconnected from the source of power for any cause. An ammeter is extremely valuable with the starting equipment to call attention to any overload on the motor, so that correction for the overload can be made before the trouble assumes serious proportions.

In reference to the cost of electric power for irrigation work, Tables III and IV give the rate used by the Montana Power Company for this class of service.

TABLE III

POWER CHARGE BASED ON CONNECTED LOAD

Month's Service	Rate Per Horse Power
1st	$2.50
2nd	2.00
3rd	1.50
4th	1.25
5th	1.00
6th	0.75
7th	0.60
8th	0.55
9th	0.50
10th	0.45
11th	0.45
12th	0.45

TABLE IV

KILOWATT HOUR CHARGE, BASED ON CONNECTED LOAD

Horse Power	Rate Per Kilowatt-hour
1 or less	$0.028
2	0.027
3	0.026
5	0.025
7½	0.023
10	0.021
15	0.019
20	0.017
25	0.016
35	0.014
50	0.0116
75	0.0098
100	0.0087
125	0.0080
150	0.0074
175	0.0071
200	0.0068
300	0.0061
500	0.0055
750	0.0051
1000	0.0050
2000	0.0048

The total charge under this schedule is the sum of the power charge and the kilowatt-hour charge.

EXAMPLE

Assume that 264 acres are to be irrigated through a total lift of 30 ft., on the basis of one second-foot for each 66 acres; this would require a pump which would deliver four second-feet (1795 g.p.m.). The brake horse power required to drive this pump, assuming a pump efficiency of 70 per cent, would be found by applying the foregoing formula, that is:

$$H\,P=\frac{G\,P\,M\times H}{3960\times E}$$, or substituting

we have

$$H\,P=\frac{1795\times 30}{3960\times .70}=19.43$$

Assume that it was necessary to pump 1½ acre-feet of water per acre per season. For 264 acres it would require a total of 396 acre-feet of water. Since the pump supplies a maximum of 1795 gallons per minute, it would have to operate a total of 1198 hours during the season.

Since the brake horse power required to drive the pump is 19.43, the kilowatt hours consumed during the season would be obtained by the following formula, assuming a motor efficiency of 86 per cent.

$$K\,W\,H=\frac{H\times 0.746\times H\,P}{E}$$

In which

$K\,W\,H$ = Kilowatt hours

H = Total number of hours motor operates

$H\,P$ = Brake horse power delivered by motor

E = Efficiency of motor expressed as a decimal.

Substituting the above values in this formula we have:

$$K\,W\,H=\frac{1198\times 0.746\times 19.43}{0.86}=20{,}191.66$$

From the above rate, based on a connected load of a 20-h.p. motor for 5 months, the total power charge would be as follows:

20 h.p. at 8.50 per h.p. per month for 5 months	$165.50
20,191.66 kw-hr. at 0.017 per kw-hr.	343.26
Total amount for power	$508.26

Fig. 5. Small Irrigation Pumping Unit; Motor 15 h.p., 90 r.p.m., 220 volt, 3 phase, 60 cycles

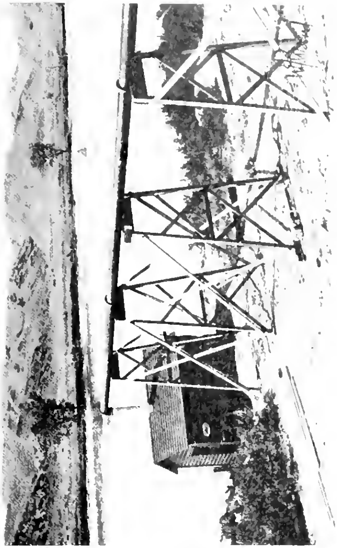


Fig. 6. Small Irrigation Pumping House

Fig. 7. A Typical Irrigation Ditch

Fig. 8. A Main Ditch and Switchback

Since we figured on putting $1\frac{1}{2}$ acre-ft. of water on each acre or a total of 261 acres and since the total cost for power is $508.26, we see that $1\frac{1}{2}$ acre-ft. of water per acre per season would cost $1.92.

For a lift twice as high the cost per acre-foot would not be twice the above amount, due to the fact that the pump would be more efficient, also the kilowatt-hour charge decreases as the horse power of the motor increases.

The first cost of irrigating equipment which will be correct for all conditions is practically impossible to give, owing to the many factors which enter when arriving at the first cost. The more important factors which govern the first cost of irrigating equipment are location of water supply with respect to location of the pumping unit, the total lift, nature of power supply, amount of water required for various crops, the expense of installation, nature of soil, etc., but the examples in Table V will serve to indicate the first cost of several plants which were recently installed along the Missouri River in the vicinity of Fort Benton, Montana.

In Table V it will be noted that power was obtained from a 13,200-volt, 3-phase, 60-cycle line in all but three instances, in which cases power was obtained from a 2300-volt, 3-phase, 60-cycle line. Additional capacity was allowed in some of the 13,200-volt transformers from that required by the motor on the pump, as power is also used for other purposes in these instances.

In order to put in the various projects mentioned above it was necessary to obtain power from a 50,000-volt line where one power transformer was installed by the Power Company to step the voltage down to 13,200 volts. From this substation it was necessary for the various ranchers to build their own line to take in the different pumping plants; this line is 32 miles long, and is owned and operated by the various ranchers, but built under the supervision of the Power Company. The line was built to handle a total of approximately 400 h. p., but when first put into operation handled a little over half this capacity. The ranchers incorporated for the total first cost of the line and issued a number of shares of stock, equal in number to the full horse power capacity of the line. The cost per share was arrived at by dividing the total cost of the line by the total horse power which the line would serve when first put in operation. Each rancher purchased a number of shares of stock equal to the horse-power rating of his motor which took care of the first cost of the line. However, when additional customers connected to the line, the new members were required to purchase a number of shares of stock equal to the horse power rating of the motor being connected. This amount received from a new connection was

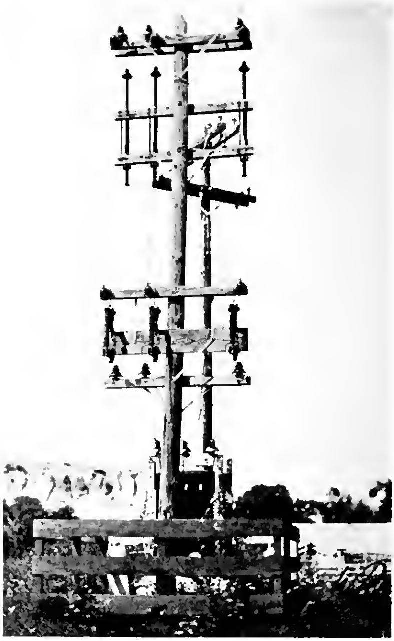


Fig. 9. Transformer, Lightning Arresters, etc., for 13,200 220-volt, 3-phase, 60-cycle Line

divided as a dividend, the new members' shares participating in the dividend. This scheme ultimately cut down the individual's cost very appreciably. The stock was made assessable by their articles of incorporation so that when it became necessary to pay more than par, an assessment was declared. For upkeep and additional expense from time to time, assessments are called for.

It was necessary to incorporate to have a guaranty of the various deeds for these rights of ways. Another feature why it was found necessary to incorporate was that in case of accident to any one from the line, providing it were to be owned by a co-partnership, each individual would be personally liable for all damages that might be suffered, whereas the corporation is liable to the extent of its assets only. For instance if a judgment should be recovered against the corporation for a certain amount, the only assets would be the power line, to be sold by the sheriff, and it could be bought in by some one of the Company for a nominal sum, as no one would care to buy a power line not interested in it. There were several other reasons why it was found necessary to incorporate, but the foregoing will serve to bring out the most important reasons.

In connection with the installations referred to, it is of interest to know that several of them replaced older installations of various kinds such as steam plants, oil engine plants and water wheels, which either proved too expensive to operate or were unreliable in operation. Excellent results have been obtained from these privately owned, electrically operated plants.

A number of large projects have been put into operation in Montana where several thousand acres are irrigated by means of a central pumping plant. An example of such an installation is the Prickley Pear Project. The Prickley Pear Project is located from [illegible] mile [illegible] of [illegible] along the [illegible] of Lake Helena. The [illegible] 8000 acres [illegible] land [illegible] in general [illegible] loam [illegible]. The [illegible] naturally [illegible] wheat, potatoes [illegible]. The growing season [illegible] available for [illegible] from May 1st to October 1st of [illegible]. The average number of heat units for the [illegible] period, taken over a ten-year period, is 2,872, as given in the Montana Experiment Bulletin No. 107.

The annual precipitation for the valley is about 10 in.; the greater portion of which falls during the months of May and June. The water supply for the project is Lake Helena, an artificial lake impounded by the 70-ft. dam at Hauser Lake, a power site of the Montana Power Company, on the Missouri River.

Two separate electrically operated pumping stations supply this project with the necessary water for irrigation. One is known as the North Unit, and the other as the South Unit; they are located about a mile apart. The North Unit supplies water for approximately 5,477 acres through three main canals, named [illegible]

TABLE V

Pump Capacity in Gal. P. M.	Total Lift in Ft.	Number Acres Irrigated	Direct-Connected or Belted	Horse Power of Motor all Squirrel Cage, 3-phase, 60-cycles	Kv. a. Capacity of Transformer [illegible] 200-volt [illegible] Primary 220/440 volt [illegible]	[illegible]	[illegible] 2,200/200 [illegible] 60-cycle [illegible] Primary Fuse with 3 2,200-volt Arrester [illegible] Ft. Benton, Mont.
1000	16.5	150	direct	10	10	$797.85	$756.80
1000	24	148	belted	15	15	885.00	816.60
1500	16	220	direct	15†	15	1011.90△	816.60
1600	14	245	direct	15	15	1024.00	922.00△
2000	17	285	direct	20	25	1064.90	1031.30
2000	21	300	belted	25*	No. trans.	1230.65	No. trans. 2200-volt service
2000	30	290	direct	30	37½	1364.40	1057.85
3000	14	400	direct	30	37½	1277.90	1057.85
2000	17	280	belted	25*	No. trans.	1140.75	No. trans. 2200-volt service
1500	22	215	direct	25*	No. trans.	1280.55	No. trans. 2200-volt service
1000	18	140	direct	10	10	809.25	756.77
2-2000	17	550	belted	40	50	770.25 Less pumps	1179.60

* 2200-volt motors.
† Vertical motor and pump.
△ Includes 2 oil pole line switches.

Canal *C* has a total lift of 155 ft., and is of 30-second-feet capacity at the beginning, and 5-second-feet capacity at the end. It is 9 miles in length. Canal *B* has a total lift of 110 ft. and is of similar size and construction to Canal *C*, and is 7 miles in length. Canal *A* has a total lift of 75 feet and is also of similar size and construction to Canal *C*, and is 4 miles in length. The three canals run parallel to one another from east to west. All these canals have a slope of 4 ft. to 1,000 ft.; the side slopes being 1½ to 1. The canals in the main follow the general contour of the land, but the cut and fill system was used to a considerable extent with numerous flumes, which vary in size from 96 in. to 45 in. The flumes are supported by standard wooden frame construction. The turnouts are of concrete construction, designed and constructed on the project.

Wood stave pipe lines convey the water from the station to the canals. The pipes are 36 in. in diameter and were constructed of Oregon fir and steel bands. The wood was not treated and the pipes buried in the soil. In this connection it is of interest to note that by the end of the sixth season, the pipe lines had badly rotted and were replaced with treated timber—redwood, unburied.

The length of pipe line *A* is 1600 ft.
The length of pipe line *B* is 2100 ft.
The length of pipe line *C* is 2900 ft.

Concrete outlets are provided at the head of the canal for each pipe line.

The pumping plant consists of a steel frame, corrugated iron structure, with a concrete foundation 60 by 45 by 35 ft., and houses the following equipment:

- One triple-pole, single-throw, 70,000-volt, 100-ampere oil circuit breaker, with overload trip.
- Three 600-h.p., 1200-r.p.m., 2200-volt, 3-phase, 60-cycle, squirrel cage induction motors.
- Three 900-kv-a., 70,000-volt primary, 2200-volt secondary, 60-cycle, single-phase, oil-cooled transformers, having taps in the secondary for 1100 and 1600 volts, which taps are used as starting taps for the motors.
- One 5-panel switchboard.
- Nine 12-in. 10-second-foot, single-stage, double-suction volute pumps.
- Three 3-kv-a., 2200-volt primary, 110 220-volt secondary, single-phase, 60-cycle, oil-cooled transformers for station lighting and vacuum pump motor.
- One 5-h.p. induction motor, direct connected to the vacuum pump.
- One 70,000-volt, 3-phase, electrolytic lightning arrester.

The pumps are arranged in three sets, three pumps to one motor. The motors and pumps are direct connected through flexible couplings. Each unit consists of:

- One 600-h.p. motor.
- One 10-second-foot, 12-inch 75-foot head volute pump.
- One 10-second-foot, 12-inch 110-foot head volute pump.
- One 10-second-foot, 12-inch 155-foot head volute pump.

The head pump is located on one side of the motor, and the two low head pumps are located on the other side of the motor. The three sets are exact duplicates of each other, and pumps for the same lifts are arranged in parallel with each other. All pumps of the same lift discharge into a common header which extends outside the station and joins the pipe line in a concrete joint. The header is constructed of steel.

The switchboard consists of five panels, namely, a primary panel on which is mounted an indicating wattmeter and integrating watthour meter, a voltmeter and operating mechanism for the primary oil circuit breaker; a 2200-volt incoming line panel; and three-motor panels; each motor panel contains a starting and running switch for the 600-h.p. motor and an ammeter. The starting and running switches on each panel are so interlocked that it is impossible to close the running switch without first closing the starting switch; this prevents the incorrect starting of the motors.

The station is operated by a single attendant, who sleeps in or near the station. Automatic alarms are provided to warn him of trouble within the station. One canal rider, who is provided with a horse, looks after the ditches, reads the wiers and reports to the project manager each day. In the station, curves of each pump are kept, which indicate the amount of discharge for each inch opening on the discharge valve stem of the pump. This scheme enables the attendant to arrive at the required amount of water for each ditch.

The South Unit supplies water for approximately 2720 acres through two miles of 90-second-foot canal; the total lift being 162 ft.

The original plans called for one main 90-second-foot canal divided at its end (the two-mile point), into two 45-second-foot canals. The plans for one of these 45-second-foot canals called for the construction of a 600-ft. tunnel through quartzite. This canal has not as yet been built, but all construction work put in provides for its future construction. The other 45-second-foot canal was put in and is seven miles in length. The canals follow the general contour of the land, using an economic cut and fill method for practically all of the excavation. There is one 96-in. flume approximately 150 ft. long. The turnouts are of the cast iron gate valve type, 14 and 16 in. in diameter and fitted to suitable tiling. The gates are provided with locks.

The wiers are of the Chippoletti type, two feet and four feet in size, and are provided with filling boxes for accurate measurements.

One wood stave pipe line constructed of untreated pipe, laid above the ground, conveys the water from the station to the head of the 90-second-foot canal. A concrete automatic syphon spillway was constructed at the end of the 90-second-foot canal. This is similar in construction to the automatic spillways used on dams, and was installed to protect the small canal from excess water, resulting from accidentally running both 45-second-foot pumps too long at the same time.

The pumping station consists of a steel frame and corrugated iron building and contains the following equipment:

- Three 900-kv-a, 70,000-volt primary, 2200-volt secondary, 60-cycle, single-phase water-cooled transformers, having taps in the secondary for 1100 volts. which taps are used as starting taps for the motors.
- Two 940-h.p., 900-r.p.m., 2200-volt, 3-phase, 60-cycle squirrel cage induction motors.
- Two 24-inch, 45-second-foot volute, single-stage pumps.
- One 4-panel switchboard.
- One 5-kv-a., 2200-volt primary, 110/220-volt secondary, 3-phase transformer.
- One 5-h.p. induction motor for driving the vacuum pump.

Just outside the station is located a pole type, triple-pole, 70,000-volt air break switch provided with fuses on the station side.

Each of the two 45-second-foot pumps are direct connected to one 940-h.p., squirrel cage motor. The two pumps discharge into a common header which runs along the floor out through the side of the station and joins the pipe line in a concrete joint.

Twenty-four-inch gate valves operated through gears and chain, by hand, are inserted in the discharge side of each pump, between the pump and the header.

The switchboard consists of four panels, namely, incoming line panel containing an integrating watthour meter, an indicating wattmeter, ammeter, voltmeter and an overload oil circuit breaker, having overload and low voltage release for controlling the incoming 2200-volt line. Panel No. 2 is an incoming line panel for the 1100-volt starting bus, and has an oil circuit breaker for controlling this circuit. Panels 3 and 4 are the 940-h.p. motor panels, each having an ammeter, a starting and running oil circuit breaker; the running side of which is provided with overload relays. The starting and running switches are so interlocked that it is impossible to close the running switch without first closing the starting switch, which will prevent the incorrect starting of the motors.

This station is operated by a single operator, and one canal rider, similar to that described for the North Unit.

The valve stems of these pumps are calibrated to read discharge in second-feet for each inch opening of the valve stem.

The water users on this project are required to give 24 hours notice when requesting water.

It has been demonstrated beyond doubt that irrigation is the best crop insurance obtainable and it has been found to be a good investment, even though water is required only once in four years.

TABLE OF EQUIVALENTS

1 acre is 208.76 feet square.
1 acre equals 43,560 square feet.
1 acre-foot equals 325,850 gals.
1 second-foot equals 40 Montana Statutory Miner's inches.
1 cubic foot of water weighs 62.5 pounds and contains 7.48 gallons.
1 second-foot equals 7.48 gallons per second; 448.8 gallons per minute; 646,272 gallons per day.
1 miner's inch equals 11.22 gallons per minute.
1 miner's inch for thirty days will cover an acre 1.49 feet deep.
1 miner's inch for the ordinary irrigating season of 150 days will cover an acre 7.436 feet deep.
1 miner's inch flowing from April to September inclusive (183 days) will cover an acre 9.072 feet deep.
1 gallon weighs 8.33 pounds.
1 gallon equals 231 cubic inches.
The horse power is the unit of mechanical energy and is the energy required to lift a weight of 550 pounds through a vertical distance of one foot in one second; 550 pounds of water dropping one foot per second would be capable of doing work to the amount of one horse power for each foot of drop.
1 second-foot falling 8.8 feet equals one horse power.
The watt is the unit of electrical energy; 746 watts equals one horse power.
The kilowatt is equal to 1000 watts, or approximately 1 1/3 horse power.
The kilowatt hour is the basis on which electrical energy is sold; it represents the use of one kilowatt for one hour.

A New Type of Stabilizer for Use With the Coolidge Tube

By W. K. Kearsley, Jr.

Research Laboratory, General Electric Company

It is highly desirable to hold a constant current in a Coolidge tube. Two stubborn factors had to be overcome before this could be accomplished—the variations in the line voltage and some means of compensating for the small quantities of gases which are liberated in the tube itself. The device described in the present article overcomes these difficulties and gives a constant current under all conditions of operation. The subject matter of our article is taken from a paper read by the author at the annual meeting of the Radiological Society at Chicago, December, 1920.—Editor.

In 1913 when Dr. Coolidge made the first tests of his hot cathode X-ray tube he found that to obtain a steady milliamperage through the tube he must keep the filament temperature steady. To this end, a storage battery was used as a source of current to heat the filament.

Storage batteries were all right in the laboratory but were far from satisfactory in the doctor's office for several reasons. The demand for something better led to the use of a "filament transformer." This device required no attention, was always ready for use and was so much better than the battery that it has now come into universal use. Substituting the filament transformer for the battery introduced the factor of line voltage fluctuations and its effect on the temperature of the filament. To eliminate or neutralize these fluctuations various types of constant current transformers or stabilizers were devised with varying degrees of success.

In all of these devices the aim was to hold a definite constant current through the filament regardless of line voltage fluctuations. This would prevent sudden changes in milliamperage through the tube due to line voltage changes, but would not take care of changes in milliamperage due to liberation of small quantities of gas in the tube during a long run.

With these facts in view it seemed clear that the ideal stabilizer would be one which would immediately correct any tendency toward a change in milliamperage caused by either line voltage or tube.

The following is a description of a new form of stabilizer which is operated directly by the high-tension current which flows through the tube. Any change in this high-tension current causes the stabilizer to act directly on the current flowing through the filament. If for any reason the high-tension current through the tube tends to drop, the stabilizer immediately increases the filament current sufficiently to prevent the drop. The same holds true for a rise in high-tension current; the filament current in this case is immediately lowered enough to keep the milliamperage at the desired value.

Fig. 1 shows diagrammatically the principle upon which the stabilizer operates. *A* is an electro-magnet which is connected directly into the high tension circuit. All of the high tension current passes through this magnet. *B* is an iron armature which is free to vibrate when current passes through the magnet *A*. *C* and *D* are contacts. One of these is fastened to armature *B* and moves with it while the other remains fixed. These contacts are in series with the filament in the X-ray tube. There is also a small fixed resistance *R* which is connected across the wires leading to the contacts. *S* is a spring

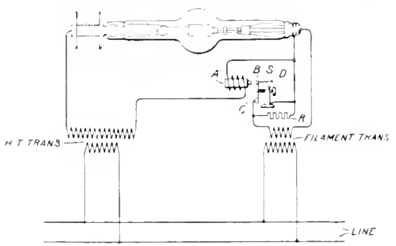


Fig 1. Diagram Showing Stabilizer in High-tension Circuit

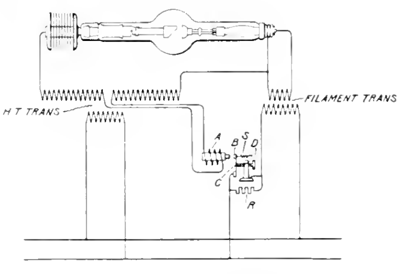


Fig. 2. Diagram Showing Stabilizer in Low-tension Circuit

which pulls the armature away from the magnet.

The operation is as follows:

We will assume that a small current of say 1 or 2 mil-amp. is allowed to flow through the tube and magnet *A*. This current exerts a pull on the armature *B*, but if the spring *S* is sufficiently strong the armature will not move. Now if the current is increased to say 10 mil-amp. the magnet overcomes the tension of spring *S*, and the armature moves toward the magnet. The instant the armature moves contacts *C* and *D* separate and the filament current, which was purposely set at a higher value than that necessary for 10 mil-amp., now has to pass through the small resistance *R*. This resistance immediately lowers the filament current, which, of course, keeps the high tension current through the tube from going higher. This operation is repeated for each cycle of high tension current passing through the tube.

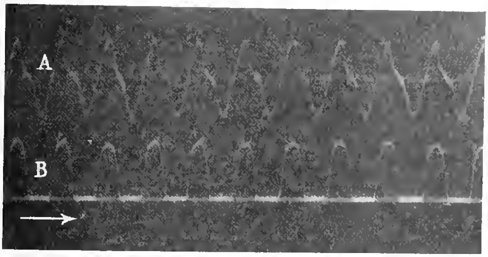


Fig. 3. Curve Made with an Oscillograph, "A" Filament Current; "B" High-tension Current Through Tube

It will be seen then that the high-tension current through the tube is controlled by the tension of spring *S*. If 20 mil-amp. is desired instead of 10 mil-amp., the tension of spring *S* is increased. More current now has to flow through the magnet before the contacts will separate. Instead of changing the tension of the spring to get more or less current through the tube, the magnet may be moved farther away from, or closer to, the armature *B* which accomplishes the same result, or the number of turns of wire on the magnet may be varied by means of one or more taps, or in other ways.

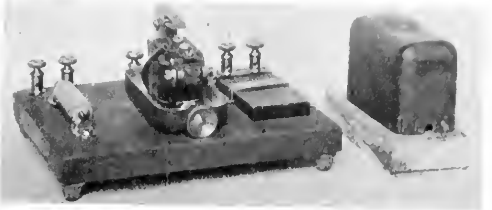


Fig. 4. Stabilizer for the Coolidge Tube (Experimental Model)

Fig. 2 shows another method of connecting the stabilizer to the tube circuits. In this case the magnet coil is connected to the center taps brought out from the high-tension winding of the transformer and the contacts *C* and *D* are inserted in series with the primary of the filament transformer. The operation is the same in either case. On those transformers having no leads brought out from the center point of the high-tension winding, it is necessary to connect the stabilizer in the high-tension lead to the cathode of the tube as shown in Fig. 1. In this case the stabilizer becomes part of the high-tension circuit.

Table I shows the effect of line voltage variations on a tube without stailblizer, and the same tube with the stabilizer in circuit.

The stabilizer in this case was set for 2.0 mil-amp.

Table II shows how the stabilizer maintains the current through a radiator type

TABLE I

WITHOUT STABILIZER		WITH STABILIZER	
Volts	Mil-amp.	Volts	Mil-amp.
77	2.2	70	2.0
80	3.3	77	2.0
82	4.3	84	2.05
84.5	6.0	87	2.05
86.5	7.0	90	2.05
89.5	8.4	93.5	2.05
91.0	10.0	96.5	2.05
92.5	11.5	99	2.05
95	13.8	103	2.05
96.6	15.0	106.5	2.05

TABLE II

WITHOUT STABILIZER		WITH STABILIZER	
Time	Mil-amp.	Time	Mil-amp.
0 min.	10.0	0 min.	10
1/2	9.6	1/2	10
1	9.3	1	10
1 1/2	9.0	1 1/2	10
2	8.7	2	10
2 1/2	8.1	2 1/2	10
3	7.0	3	10

tube during a long exposure. The tube was first connected to a filament control rheostat in the regular way and the current adjusted to 10 mil-amp. Readings were then taken every half minute up to three minutes. The tube was then allowed to cool and the stabilizer connected in circuit. Current was adjusted to 10 mil-amp. and readings were taken again.

Fig. 5 shows a curve made with an oscillograph. The tube was of the self rectifying type. The lower curve represents a high tension current of 15 mil-amp. through the tube, and the upper one, the filament current taken at the same time. The small irregular lines in the filament current curve show the points at which the stabilizer contacts opened to prevent a further rise in milliamperage through the tube. It will be noticed that there is a break in the filament current curve for each cycle of current through the tube. This shows that the vibrating armature vibrates in synchronism with the alternating current supplying the tube. This is important. If the armature did not vibrate in synchronism, the filament current would not be adjusted to the correct value on some of the cycles, which would cause a variation in the milliamperage through the tube.

That the stabilizer does produce an even flow of current through the tube, even though the filament current is changed on each cycle, is shown by the evenness of the peaks of the waves in the lower curve, which is the curve of the high tension current.

Summary

In the foregoing, a stabilizer has been described which is operated directly by the high tension current which flows through the tube. Using the milliamperage as the controlling element the stabilizer maintains the desired current through the tube regardless of changes either in the line voltage or in the tube itself.

It can be made small and it requires a negligible amount of energy for its operation.

It should prove useful wherever it is desirable to automatically maintain a definite amount of current through a Coolidge Tube.

A Paint That Will Not Reflect Ultra Violet Rays

By W. S. Andrews

Consulting Engineering Department, General Electric Company

The dangerous invisible rays of ultra-violet light, as produced by the electric arc in welding of iron or steel, can be reflected in the same way as visible light. Ordinary spectacles do not, therefore, provide entire protection to the eyes, because they fail to obstruct the rays which may be reflected from objects in a sidewise direction and in many cases these rays may have a dangerous intensity. For this reason operators should always wear goggles to cut off these side reflections, and when engaged on heavy welding work, suitable helmets or masks, and gloves should be worn to protect the otherwise exposed skin of face, neck, hands and arms.

Almost all surfaces that reflect visible light will also reflect the invisible ultra-violet rays to a greater or lesser extent, but there is at least one material which, although pure white, absorbs them completely, so that it would appear jet black if we could see it by this light alone. This material is zinc oxide or Chinese white, and its curious property, as above stated, was discovered by Professor R. W. Wood. While experimenting along these lines, he covered surfaces with various white paints such as white lead, lime, zinc oxide, etc., and found that although they could hardly be distinguished one from the other under visible light, strange to say, the surface painted with zinc oxide absorbed all the ultra-violet radiation, so that it reflected practically nothing but harmless visible light.

As a further source of safety to operators and chance lookers-on, it is evidently desirable that the walls and ceilings of shops where electric arc welding work is done should be covered with a paint that will absorb the ultra-violet radiations, so that their reflecting power may be reduced to a minimum. Paint made with zinc oxide, that is, Chinese white, will answer this end, but pure white would naturally produce too dazzling an effect, so it is best to tone it down to a light gray with lampblack, which only slightly affects its ultra-violet absorbing quality. Also the paint must be mixed so as to produce a dead surface, as even Chinese white when made so that it dries with a glossy surface, will reflect the dangerous rays. Perhaps the best adhesive medium is glue water, such as is used with lime for kalsomining, as this is cheaper than oil, and the paint so made will dry with a smooth unglazed surface. For covering any considerable wall surface it will be found convenient and economical to apply it with a paint sprayer.

The Ratio Adjuster

By A. E. Wing

Transformer Engineering Department, Pittsfield Works, General Electric Company

The device described in this article has been developed to provide a convenient means of changing the ratio of a transformer. The common practice has been to bring the taps from the transformer windings to a terminal board located under the oil, the change in connection being made directly by hand. This procedure was quite often inconvenient and uncomfortable and attended by the liability of making wrong connections. The ratio adjuster accomplishes the change of connections through a fractional turn of a handle located above the surface of the oil, which is readily accessible, thoroughly insulated, and which carries a pointer indicating the connections for the various positions.—Editor.

Heretofore, the usual method of changing the ratio of a transformer to compensate for voltage drop in transmission has been by means of taps in either the high or the low voltage winding brought to a terminal board under oil where a part of the winding could be cut out of use.

Fig. 1. Small 33-kv. Transformer Ready for Tank, Showing 15-amp. Ratio Adjuster

Some of the disadvantages of this means of adjusting the ratio are:

First.—The terminal board must be under oil, which requires that the operator either must put his hand in the hot oil to change connections that are not always visible, or he is put to the inconvenience of lowering the oil below the terminal board.

Second.—The terminal board is many times necessarily almost inaccessible, especially if the connections of the transformer are very complicated and the voltage is high.

Third.—The operator is liable to drop a nut or a connector into the windings of the transformer.

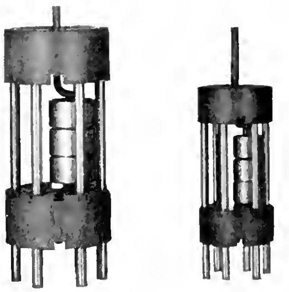


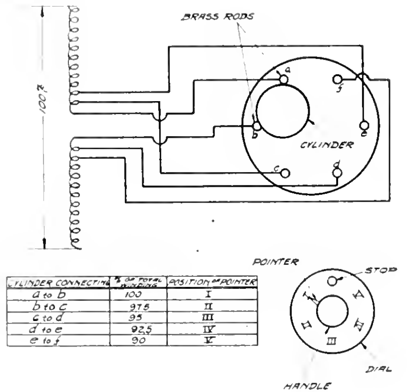
Fig. 2. Ratio Adjuster Units, 25 and 15 amp.

Fourth. Unless the terminal board has been made "fool proof" it is possible for the operator to make a wrong connection, either short circuiting a part of the winding or leaving the winding open.

Fifth. The contact parts may not be properly tightened.

Recognizing these disadvantages it has long been the opinion of many engineers that a thoroughly reliable device was needed whereby the tap connections could be easily and accurately changed without the necessity of having any live parts above the oil or windings. A device has been recently designed which fulfills all of these requirements. As it is not, however, intended for changing the connections while the transformer is under excitation, it cannot correctly be termed a switch and has therefore been called the ratio adjuster.

The ratio adjuster (see Fig. 1) is a simple and compact device so designed that all tap connections can easily be changed by the fractional turn of a handle above the surface of the oil near a hand-hole opening in the cover of the transformer. It consists of a heavy



CYLINDER CONNECTING	% OF TOTAL WINDING	POSITION OF POINTER
a to b	100	I
b to c	975	II
c to d	95	III
d to e	92.5	IV
e to f	90	V

Fig. 3. Diagram of Connections for Ratio Adjuster

insulating tube containing a connector mechanism which is joined to the handle above the oil level by a long insulating rod. The handle carries a pointer that sweeps over the surface of a dial to indicate the position of the connection below.

The connector mechanism is the important part of the adjuster. It consists of two thick discs of insulating material that hold several vertical brass rods equally spaced in the outer circumference, the whole forming a cage-like frame (see Fig. 2). The rods extend through the bottom support, providing a means for attaching them to the various taps in the transformer winding. Within the cage is a crank supported in the center of the discs. On the offset of this crank are several cylinders enclosing springs, which force them into place between the rods as the crank carries them from one position to the next. The cylinders provide a rolling contact against the rods, which is preferable to a sliding contact because it precludes the possibility of the connectors remaining in an open circuit position. The connectors fall into place with a positive snap, and it is impossible to leave the contacts midway between positions.

The taps from the transformer winding are permanently attached to the vertical rods, and all designed connections can be made by rotating the contact cylinders without possibility of making either a short or an open circuit (see Fig. 3). The standard adjuster is designed to accommodate four taps. When less than four are brought out from the winding, an open circuit is avoided by properly placed stops that limit the sweep of the pointer over the dial. When more than four taps are required, two or more adjusters may be used.

The contact-making mechanism is supported near the location of the taps thereby eliminating long tap leads and a live terminal board above the transformer core (see Fig. 4).

The adjuster is designed with ample contact surface to carry any momentary short circuit current that may occur in the winding to which it is attached, without damage to the contacts. This is made possible in very compact form by the self aligning feature and the large radiating surface of the contacts.

Fig. 4. Large 13,800-volt Transformer Ready for Tank, High-voltage Side, Showing 100-amp. Ratio Adjuster

The taps are brought out of the body in the winding (not at the ends) so as to avoid the abnormal voltage transients to which the end turns are subjected from the transmission line. The ratio adjuster, because of its contact-making function, can have no solid insulation between contacts, as would be required to delay arc-over if placed at the ends of the winding.

The adjuster has been successfully used with many thousand transformers up to 200 kv-a. and 44,000 volts. Its use as a standard feature has now been extended to cover the majority of single and three-phase transformers from 10 to 500 kv-a., 13,200 volts and higher. Ultimately the adjuster will be standard on all units from 10 to 500 kv-a., 6000 volts and above.

The following sizes of ratio adjuster have been designed as standard

Current Carrying Capacity in Amperes	Transformer Rating in Kv-a.
10 at	17 or less
15 at	25 or less
25 at	37 or less
50 at	50 or less
100 at	73 or less
200 at	115 or less
500 at	37 or less
500 at	73 or less

Devices for Measuring Turns of Coils

By S. C. Hoare

Standardizing Laboratory, Lynn Works, General Electric Company

Laboratory methods are usually developed having regard to extreme accuracy rather than speed, and many of these methods while entirely satisfactory for laboratory use are too laborious and slow for factory production. This is true of the ballistic galvanometer method of determining the number of turns in coils, and other methods more expeditious have had to be developed. This article describes three of these methods, one of which is suitable for work where accuracy greater than 99 per cent is not required; the other two methods being more sensitive are peculiarly well adapted for testing the coils of electrical instruments.—Editor.

The usual method of measuring the number of turns in a coil with the aid of the ballistic galvanometer, though very accurate, is much too slow and laborious for general shop practice. This method consists simply in threading the coil under test, together with a standard coil, over the middle section of a long air-core solenoid which acts as the primary coil. This arrangement may be used in two different ways, viz., a null method where the unknown and standard coils are connected in series opposition and the standard is adjusted so that upon suddenly reversing the current in the solenoid no galvanometer deflection is noted (Fig. 1); and a comparative method where the deflections of the galvanometer, when connected to each coil separately through suitable series resistance, are noted (Fig. 2).

Both methods require much care and patience, and therefore are wholly unsuited for uses outside of the laboratory. More detailed information concerning the ballistic methods may be found in any standard text book on electrical testing. Present day construction of various types of electrical apparatus demand devices for quickly and accurately checking the finished coils in the factory inspection departments.

All the devices to be described are designed for use on a standard 110-volt, 60-cycle supply line. With slight changes they may be adapted for almost any voltage or frequency.

An arrangement developed for checking motor field coils where precision greater than 99 per cent is not required is shown in Fig. 3. Here P is a long iron core solenoid serving as a transformer primary connected across a factory alternating-current source. This core, having an open magnetic circuit, is made relatively long in comparison with its cross section to insure uniformity of magnetic flux near the middle part where the coils S and X are placed.

The unknown X and standard S are each connected to a high resistance voltmeter. That connected to S has a single index mark on its scale, while that to X is marked in turns.

The iron core is set up in a vertical position with one-half of its length below the work bench. The standard coil being permanently fixed in position (in this particular case), the operator merely drops the unknown coil over the coil to the middle part and inserts the leads into the terminals, thus making connection with the indicating instrument. By varying the rheostat the pointer of the standard instrument is brought to the index mark The number of turns is then very accurately read on the other instrument.

The resistance of these instruments are of such high values that errors due to variations in resistance of the coils themselves are negligible.

When once the pointer of the standard is adjusted, the deflection of the other due to X

depends solely upon the ratio of the turns of X to S. With the pointer on the index, the primary voltage is constant and variation in voltage of the source is compensated in the

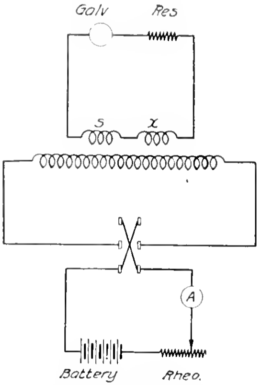


Fig. 1. Connection Diagram of the Ballistic Null Method

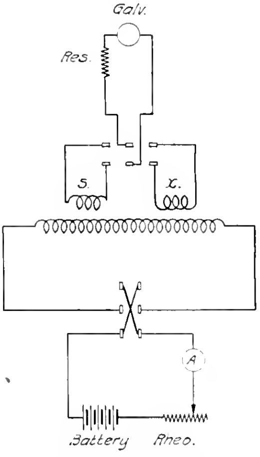


Fig. 2. Connection Diagram of the Ballistic Comparative Method

rheostat. Any variation in frequency affects the induced e.m.f. in coil S and X in the same proportion. A variation in frequency can be compensated for by an inverse variation in exciting current. Hence, the one rheostat compensates for both voltage and frequency changes.

The drawbacks to the device might be summed up as follows:

1. The source of supply must be steady

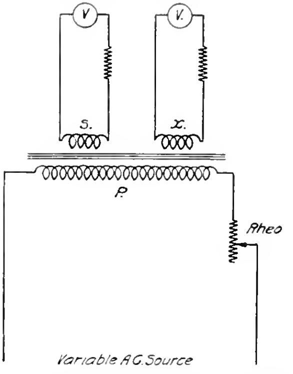


Fig. 3. Connection Diagram of a Device for Measuring Turns of Coils Within a Precision of 99 Per Cent

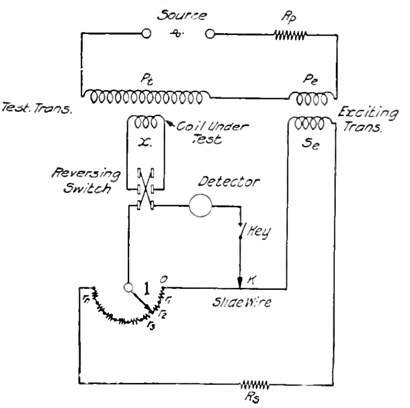


Fig. 4. Connection Diagram of a Turn-counting Device of Greater Precision Than That Shown in Fig. 3

enough to enable one operator to read both instruments simultaneously.

2. It is not a "zero" instrument and its calibration must be checked from time to time.

3. Precision greater than 99.5 cent is usually not easily obtained.

The coils used in meters and instruments cover a wide range, both in resistance and number of turns. For this class of work the device shown in Fig. 4 was developed.

It forms in reality an alternating-current potentiometer, the volt drop over the slide wire balancing the induced e.m.f. in the unknown coil X. Both test and exciting transformers are of the air core type. The test transformer primary consists of a rather long multi-layer solenoid set up in a position to allow the coil under test to be easily threaded over the middle point. The exciting transformer is of short length and of such design that the load due to the slide wire circuit is inappreciable. R_s is a resistance for adjusting the current in the slide wire, and when once made this adjustment is permanent.

value of r representing 100 turns. This particular instrument is adjusted for measuring values up to 2010 turns, though the range could be extended by adding another tap switch to take care of additional r resistances. The maximum range of the device depends upon the ratio of the exciting transformer.

Any sensitive alternating-current instrument will serve as detector. In this one an alternating-current galvanometer is used.

The complete device with the exception of test transformer and detector is contained within one case and has much the same appearance as the ordinary direct-current potentiometer (Fig. 5).

In Fig. 5 the radial switch at the left is the slide wire extension, the coil lead reversing switch is near the center, and the detector

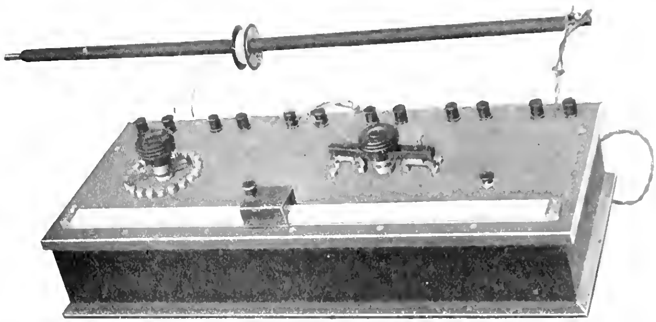


Fig. 5. Special Potentiometer, Based on Fig. 4, for Counting the Number of Turns in Instrument Coils

circuit key at the right. The test primary with an unknown coil under test is shown at the back of the case.

The turn counter is adjusted and calibrated in somewhat the same manner as the ordinary direct-current potentiometer. First, each coil of the slide wire extension, $r_1, r_2, \ldots r_n$, is closely adjusted to equal 90 per cent of the slide wire resistance. They are made 90 per cent to allow 10 per cent overlap in the slide wire. Now placing a standard coil of 100 turns in place of X, and setting arm l on r_1 and k on 0, the current in the slide wire circuit is adjusted by means of R_s such that the detector indicates zero. R_s is then permanently installed within the instrument case. Finally the arm l is set to 0 and slider k is moved along the wire to again balance the detector. This point is marked 100 and the rest of the slide wire is graduated uniformly from 0 to 110 turns. Thus the slide wire takes care of all turns up to 110. In going to higher values, the arm l is turned to $r_1, r_2, \ldots r_n$, each

The chief advantages of this type of turn counter are that it is quite sensitive and possesses a long range. It also maintains the same sensitivity over this long range. Hence, one turn deviation may be detected in a 1000-turn coil equally as well as in one of 10 turns. Any voltage variation of the source affects the drop over the slide wire and the e.m.f. in coil X in the same proportion, and thus the point of balance remains unchanged. Moderate changes in frequency also introduce no errors as they affect both sets of circuits alike. Though a wide variation in frequency would upset the phase angles, precise adjustment is not necessary as the frequency variation of the factory supply line is relatively small.

Its disadvantages are that it is more or less slow in operation. As best results are obtained with a reflecting galvanometer as a detector, it requires special care and maintenance.

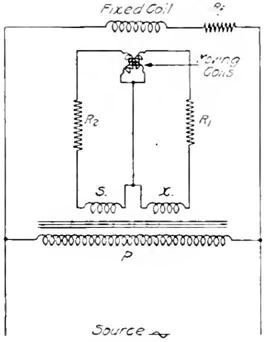


Fig. 6. Connection Diagram of Another Turn-counting Device of Greater Precision Than That Shown in Fig. 3

For testing coils where quick results of very high accuracy are required, still another instrument has been developed. This instrument is intended for those places where it is essential to detect a deviation of a fraction of one turn and where many coils of similar specification are to be tested. The principle of this instrument is shown in Fig. 6. P is the iron core primary coil encircled by the unknown and standard coils X and S. These two coils are connected to the two movable coils of an indicating instrument. The movable coils are mounted on the same staff at an angle to each other.

In series with each leg are resistances R_1 and R_2, which serve to decrease the temperature coefficient of the device as a whole, and are sufficiently high to eliminate errors due to variations in the resistance of coils X and S.

The moving system has no control spring, and therefore the pointer remains anywhere on the scale after removing the excitation. Across the voltage source are connected the fixed coils in series with the necessary resistance. This arrangement allows of increased torque.

Use is made of a tertiary coil placed on the same core to obtain a long scale. This coil is connected in series opposition with the unknown coil X and has a less number of turns, depending upon the length of scale desired. The effective turns of this combination are thus brought to a lower value and the standard coil S is also made equal to this effective value. With this arrangement a small variation in coil X becomes a large variation in the effective turns of the combination. As an illustration, with X and S each of 100 turns, a variation of one turn in X equals 1 per cent. By using a tertiary coil of 90 turns the effective turns in X equal 10. With the standard now 10 turns, a variation of one turn in X produces a variation of 10 per cent. By this means it is possible to make a scale length of 3 inches per turn variation in the unknown. However, this great sensitivity is usually unnecessary.

The instrument as ordinarily adjusted has a scale displacement of $3/8$ in. per turn. This is usually all the sensitivity required and permits of $1/4$ turn being detected. The distribution and location of the scale is adjusted by changing the angle between the two movable coils and by turning the combination around on the staff.

Where the instrument is used to measure coils of only one specification, the scale can be marked in terms of per cent of the nominal value instead of in actual turns. Of these devices the last is the simplest to use, the operator merely placing the coil in position, closing the circuit, and noting the instrument reading. He makes no adjustments of any sort. One disadvantage is the necessity of having an accurate standard coil for each kind of coil that may be tested.

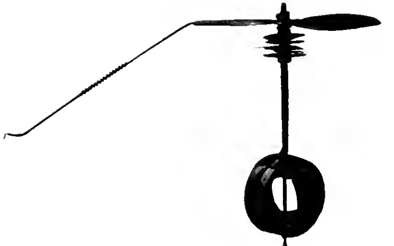


Fig. 7. Moving Element of Turn Counter Constructed in Accordance with Fig. 6

Synchronous Motor Starting Torque Characteristics

By O. E. Shirley

Alternating-current Engineering Department, [illegible]

The progress which in late years has been made in the [illegible] highly efficient and power-factor corrective machine to be applied [illegible] by reason of heavy starting torque requirements [illegible] necessary. As the resistance of the amortisseur winding [illegible] torque characteristics, considerable importance [illegible] Mr. Shirley outlines below a new testing method which will [illegible] necessary data and which is free from the disadvantages of [illegible]

The use of synchronous motors has been extended to a great many new applications during the past few years, and in a number of these cases the starting-torque requirements are quite severe. In some applications the starting requirements are heavy while the remainder of the cycle is comparatively light, and in others the starting torque may be low but that required at the higher speeds is quite high. These different requirements make it necessary that the designer know the shape of the required torque curve, as well as the actual values, if a properly designed starting winding is to be obtained.

It is a well known fact that a high-resistance amortisseur winding gives high starting torque with low pull-in torque, while a low-resistance winding will lower the starting torque and increase the pull-in torque. The maximum torque is approximately the same with either winding, but comes at a different speed.

The pull-in torque of a synchronous motor may be further increased by closing the field winding through a resistance. The value of resistance that will give the maximum torque depends, of course, on the particular design of motor. This value may be determined for any particular motor installation by finding by test the resistance which will bring the motor to the highest speed. However, since the use of resistance decreases the torque at starting, it is preferable that the field circuit be left open until the rotor has reached its maximum speed, due to the torque of the amortisseur winding only.

The determination of the torque characteristics of a synchronous motor, as it comes up to speed, is usually made by what is known as a "Running Torque Test." The motor is connected to a direct-current generator, and operated as an induction motor at reduced voltage. The load on the generator is increased by steps and readings taken of input to the motor, output from the generator and the speed. From these readings the torque curve can be obtained by well known methods.

This method of testing is subject to two marked disadvantages: it is usually difficult and expensive to make the tests, and the motor must be operated with high currents in the amortisseur windings for longer periods than the winding can stand without excessive heating.

The following method of determining the torque characteristics from test obviates both of the disadvantages just mentioned, and gives results which in most cases are practically as accurate as those obtained from the running torque test.

Method of Testing

The torque of a motor expressed in synchronous kilowatts is equal to the rotor input, and is, therefore, equal to the input to the stator minus the losses in the stator. These stator losses are usually comparatively small and may be easily determined, hence the torque of the motor can be obtained from readings of stator input as accurately as necessary for practically all applications of the motors.

This makes it practicable to obtain the entire torque characteristic of a synchronous motor simply by holding the impressed voltage constant and reading stator current, stator kilowatt input, and rotor speed as the motor comes up to synchronous speed. It usually requires from 15 seconds to two minutes for a motor without load to accelerate to full speed, and readings can be easily taken at five-second intervals, hence a very satisfactory input curve can be obtained on practically any motor. If the motor is connected to a load, the time of acceleration will be increased, but since the torque curve is obtained from simultaneous values of input and speed, the presence of the load does not complicate the testing. Since it requires only a few minutes to run any one curve, it is possible to obtain data on a motor for a number of different starting conditions in a very short time. The amortisseur winding is required to carry current only for the time of a normal starting cycle, therefore there is no liability of overheating this winding.

The limitation of this method is of course the assumption that all of the rotor input is polyphase, because the force resulting from

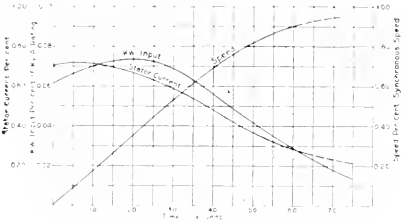


Fig. 1. Starting Test Curves, with Respect to Time, for a 1250-kv-a., 25-cycle, 6400-volt, 300-r.p.m. Synchronous Motor at 24.4 per cent Voltage

a single-phase component of input is radial and not tangential. However, with a properly designed rotor and a balanced polyphase supply, the accuracy of the test is usually sufficient for any practical purpose.

Example of Tests and Calculations

The application of this method of testing to a 1250-kv-a. synchronous motor, part of a frequency converter, will be given together

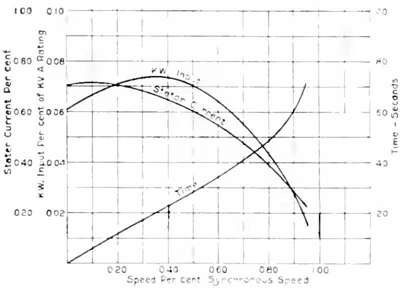


Fig. 2. Starting Test Curves, with Respect to Speed, for a 1250-kv-a. 25-cycle, 6400-volt, 300-r.p.m. Synchronous Motor at 24.4 per cent Voltage

with the calculations for obtaining the torque characteristic from the test data. The curves and calculations are all made on the percentage basis, which is usually most convenient for this work and gives a very good means of checking the accuracy of the tests and calculations. It should be especially noted that in the calculations and curves the percentage is expressed as a decimal fraction; that is, 0.10 = 10 per cent.

The actual readings of stator current, kilowatt input to stator, and speed are given in Table I together with the per cent values. The stator current is expressed in per cent of the rated current at 1250 kv-a. 6400 volts, the kilowatt input in per cent of kilovolt-ampere input rating, and the speed in per cent of synchronous speed. The per cent values are plotted in Fig. 1. Since the torque is usually desired as a function of the speed, the results are transferred to Fig. 2, which is plotted with speed as abscissas.

Table II shows the calculation of the rotor input, which is the stator input minus the stator I^2R loss and short-circuit core loss. Since the motor is started at only 24.4 per cent of normal voltage, the stator core loss is negligible. It has been found from comparisons of running torque tests with tests made by this method that the results obtained are practically the same for motors with well designed rotors.

The values of rotor input, which also is the torque in synchronous kilowatts from Table II, are plotted in Fig. 3. The rotor I^2R loss is equal to the rotor input multiplied by the slip. The friction and windage at normal speed is from test data, and the values for the lower speeds are assumed. The total rotor loss is the sum of the I^2R loss and the

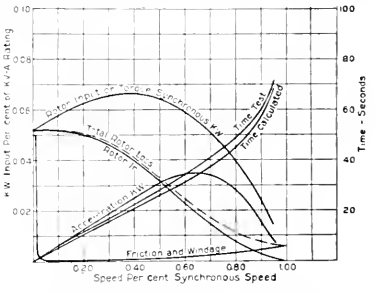


Fig. 3. Curves for Calculation of Speed-time Curve of a 1250-kv-a., 25-cycle, 6400-volt, 300-r.p.m., Synchronous Motor. Data for 24.4 per cent Voltage

friction and windage. The difference between the total input and the total loss in the rotor represents the kilowatts available for acceleration of the rotor. This acceleration kilowatt curve is also given in Fig. 3.

The time required to accelerate the rotor running without load may be calculated from the moment of inertia of the rotor and the acceleration kilowatt curve. The calculated speed-time curve is plotted in Fig. 3 and very closely checks the test curve. The method of calculation of this speed-time curve is quite interesting and is given in the appendix.

the heating of the amortisseur winding during the starting period may be estimated approximately.

The speed-time curve as derived is of interest generally only to the designing engineer, but if the motor is connected to a variable load, such as a compressor, the curve of the torque required by the load may be

TABLE I

STARTING TEST DATA

Voltage Held at 1560 Volts = 24.4 Per Cent

Time Seconds	Stator Current Per Cent: Amps	Stator Current Per Cent: 0.10 = 10 Per Cent	Input Per Cent: Kw.	Input Per Cent: 0.10 = 10 Per Cent	Tachometer Reading	Speed—Per Cent 0.10 = 10 Per Cent
0	78	0.69	76	0.061	0	0
5	80.5	0.72	81	0.065	90	0.10
10	80	0.71	87	0.070	170	0.18
15	79	0.70	90	0.072	240	0.26
20	76	0.68	92	0.074	320	0.35
25	68	0.60	90	0.072	410	0.45
30	66	0.58	90	0.072	500	0.54
35	61	0.54	80	0.064	550	0.60
40	53	0.47	64	0.051	640	0.70
45	48	0.42	60	0.048	700	0.76
50	42	0.37	54	0.043	750	0.82
55	40	0.35	44	0.035	810	0.88
60	30	0.27	38	0.030	830	0.90
65	28	0.25	30	0.024	855	0.93
70			24	0.019		
75			16	0.013		

Tachometer 918 = Speed 299 r.p.m.

TABLE II

CALCULATION OF ROTOR INPUT, KV-A. INPUT AND POWER-FACTOR

Speed Per Cent	Kw. Input Per Cent	Stator Current Per Cent	Stator I^2R + Short Circuit Core Loss Per Cent	Rotor Input Per Cent	Voltage Per Cent	Kv-a. Per Cent	Power-factor
0	0.061	0.70	0.008	0.053		0.171	0.36
10	0.067	0.71	0.009	0.058		0.174	0.38
20	0.071	0.71	0.009	0.062		0.174	0.41
30	0.073	0.68	0.008	0.065		0.166	0.44
40	0.074	0.65	0.007	0.067		0.159	0.46
50	0.070	0.60	0.006	0.064		0.146	0.48
60	0.064	0.55	0.005	0.059		0.134	0.48
70	0.055	0.48	0.004	0.051		0.117	0.47
80	0.044	0.39	0.003	0.041		0.095	0.46
90	0.028	0.28	0.002	0.026		0.068	0.41
95	0.016	0.22	0.001	0.015	0.244	0.004	0.30

In per cent 0.10 = 10 per cent.

Conclusions and Notes

The method of testing outlined gives a very convenient and quite accurate means of obtaining the torque characteristics of a synchronous motor without danger of injury to the amortisseur winding.

From Fig. 3 it is possible to derive the curve of rotor loss plotted against time from which estimated by separating the rotor loss and acceleration kilowatts from the total rotor input. The WR^2 or moment of inertia of the rotor can be obtained from the manufacturer, and from this data and the test rotor input and the speed-time curves the acceleration kilowatts can be calculated.

Appendix: Calculation of Speed-time Curve

The energy of rotation of a mass expressed in kilowatt-seconds is given by the equation

$$En = \frac{0.233\ N^2WR^2}{10^6}$$

where

N = r.p.m.

WR^2 = moment of inertia in lb. ft.^{2}

Let t_o = time that the stored energy of the rotor will give a kilowatt output equal to the kilovolt-ampere rating of the machine.

Note that 2 t_o is the time required to stop the rotor by applying a constant torque corresponding to a kilowatt output equal to the kilovolt-ampere rating. In other words, this constant torque is

$$\frac{7040 \times \text{kv-a. rating}}{\text{r.p.m.}}$$

Then $t_o = \frac{En}{\text{kv-a. rating}}$

Since the energy of the rotating mass is proportional to the square of the speed, the energy at 10 per cent speed is 0.01 of the energy at normal speed, and the energy at 20 per cent speed is 0.04 of the energy at normal speed. Hence the change in energy from zero to 10 per cent speed is 0.01 and the change in energy from 10 to 20 per cent speed is 0.04 − 0.01 or 0.03. The change in energy expressed in per cent as a decimal for 10 per cent intervals of speed from zero to 90 per cent speed is given as K in Table III. The change from 90 to 95 per cent speed is derived similarly, and is also given in this table.

The actual change in energy in kilowatt-seconds during any interval is $K\ En$.

The average acceleration kilowatts in per cent may be read from the curve in Fig. 3, and the actual acceleration kilowatts is equal to Acc'l Kw. per cent (acceleration kilowatts in per cent) times the kilovolt-ampere rating.

Then the time t for accelerating during any interval is equal to the accelerating energy in kilowatt-seconds divided by the average kilowatts during that interval.

Then $t = \frac{K\ En}{\text{Acc'l kw. per cent} \times \text{kv-a. rating}}$

But $\frac{K\ En}{\text{kv-a. rating}} = K\ t_o$

Hence $t = \frac{K\ t_o}{\text{Acc'l kw. per cent}}$

As illustrated in Table III, the time of acceleration for each of the various intervals may be calculated, and a summation of these values gives the speed-time curve. The interval in speed must be small enough so that the average kilowatts over the time interval is approximately equal to the kilowatts for the average speed. The intervals chosen in Table III give very satisfactory results. A comparison of the test and calculated curves in Fig. 3 shows that the calculated curve is very close to the test curve in both shape and actual values.

TABLE III

CALCULATION OF SPEED-TIME CURVE

$$En = \frac{0.233\ N^2WR^2}{10^6} = \frac{0.233 \times 300^2 \times 94000}{10^6} = 1980 \text{ kw.-sec.}$$

$WR^2 = 94000$

$N = 300$

$$t_o = \frac{En}{\text{kv-a. rating}} = \frac{1980}{1250} = 1.58$$

Speed Per Cent	K	Kt_o	Acc'l Kw. Per Cent 0.10 = 10 Per Cent	Seconds for Interval	Total Seconds
0.10	0.01	0.0158	0.003	5.3	5.3
0.20	0.03	0.0475	0.009	5.3	10.6
0.30	0.05	0.079	0.016	5.0	15.6
0.40	0.07	0.111	0.022	5.0	20.6
0.50	0.09	0.142	0.028	5.1	25.7
0.60	0.11	0.173	0.033	5.2	30.9
0.70	0.13	0.205	0.035	5.9	36.8
0.80	0.15	0.236	0.032	7.4	44.2
0.90	0.17	0.268	0.022	12.2	56.4
0.95	0.0925	0.146	0.012	12.1	68.5

Review of Operating Data on B. & O. R. R. Electrification

By J. H. Davis

Electrical Engineer, Baltimore & Ohio Railroad

In view of the comparatively recent electrification of many railroads to avoid the smoke nuisance, to relieve main-line congestion, to conserve fuel and otherwise lower operating costs, the information contained in the following article is very instructive because it traces to date the operation of the first main line electrification. Description is given of the changes that have been made in the power supply, line equipment, and locomotives as practice has advanced over a twenty-five year period. Data of traffic conditions, and of locomotive cost of operation and maintenance over the last ten-year period are included in tabular form.—Editor.

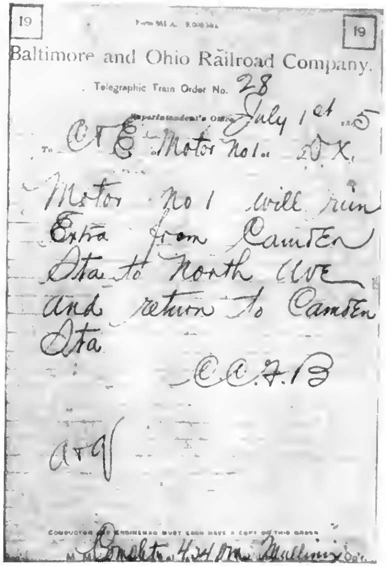
History

The Baltimore and Ohio was the first trunk railroad to adopt electricity as a motive power. This historic event occurred in the early nineties in connection with the building of its Belt Line through the city to furnish a direct rail connection between the main line west of Baltimore and that east. Previous to this, it was necessary to ferry trains across an arm of the Patapsco River. One of the requirements of the ordinance governing the construction of the line through the city was that the trains be operated electrically. In addition, the number and length of tunnels necessitated special means for reducing the amount of smoke and gases for which electrification undoubtedly offered the most satisfactory solution.

The first trial trip with electric locomotive No. 1 was made on June 27, 1894. The line was opened for traffic May 1, 1895. Three 96-ton gearless locomotives were used in this connection for handling eastbound (up-grade) trains. Westbound (down-grade) trains were handled by steam power as at present. After fifteen years' service the original locomotives were retired. One of them, however, has been preserved in good condition for exhibition purposes as being the first electric locomotive used in this country under steam railroad conditions.

Physical Characteristics

That portion of the Baltimore and Ohio Railroad which is electrified lies within the city limits of Baltimore and is a part of the so-called Belt Line, extending from Camden station on the west to Waverly interlocking tower on the east, a distance of 3.75 miles. There are eight tunnels in this zone together amounting to 48 per cent of the total distance, the longest tunnel, which is between Camden Station and Mt. Royal Station, being 7,300 ft. in length. This tunnel contains two tracks while there are four tracks between Mt. Royal and Huntington Avenue from which point to Waverly there are two tracks. That part of the zone through which trains are handled by electric locomotives is entirely up-grade, the difference in elevation amount-


19 19

Baltimore and Ohio Railroad Company.

Telegraphic Train Order No. 28

Superintendent's Office July 1st 1895

To C & E Motor No 1 at D X

Motor No 1 will run Extra from Camden Sta to North Ave and return to Camden Sta.

C.C.F.B.

A T G

Conductor and Engineman must each have a copy of this order

Complete 4.24 PM Mullin

Fig. 1 Reproduction of the First Train Order Ever Issued for the Movement of an Electric Locomotive on a Trunk Line Railroad

ing to 150 ft., which gives an average through grade of 0.9 per cent, the ruling grade being 1.5 per cent and the maximum curvature 10 deg. 16 min. Especial attention is called to this fact as trains are handled electrically in only the up-grade direction, the electric locomotives returning light which results in a unit power consumption that is in all probability larger than that for most of the existing steam railroad electrifications. Fig. 2 shows the location of this line under the city of Baltimore, the profile, number of tracks, grades, etc.

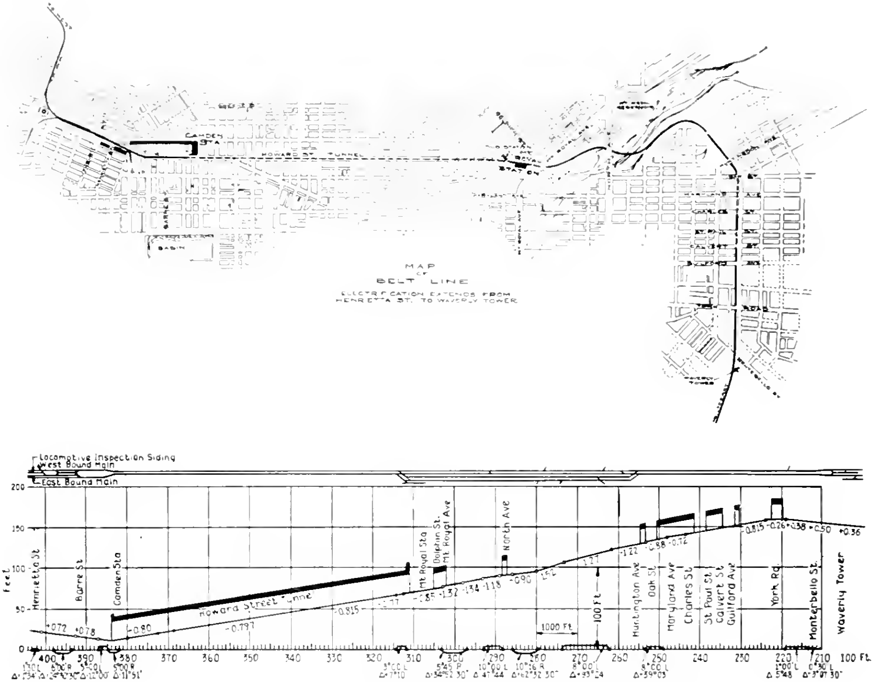


Fig. 2. Map, Track Chart, Profile, and Curvature of the Belt Line, Baltimore, Md.

struction and in the tunnels by direct hangers. In this overhead slot the collector shoe, attached to the locomotive by a pantograph, was allowed to slide. As would be expected from our present knowledge of methods of collecting current, the system was unsatisfactory and the presence of gases from steam locomotives resulted in high maintenance cost. In 1908 the overhead conductors were replaced by a third-rail system, the major portion of which is still in service. After about ten years' service the third rail in the Howard Street tunnel became so badly corroded, due to action of locomotive gases and electrolysis, that it became necessary to completely renew it, at which time the type of insulator and guard board support were modified to overcome certain faults in the original design.

System

The direct-current system is used, 675 volts being maintained at the substation bus bars at Mt. Royal, approximately the center of the electrified zone. In the original installation electric energy was supplied to the locomotives through an overhead system of power distribution. The contact conductor consisted of two "Z" bars so arranged as to form a box-like structure with a slot in the bottom. Outside of the tunnels this was supported from towers by catenary con-

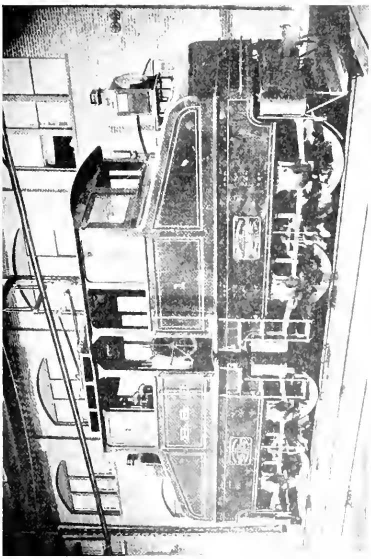


Fig. 3. First Heavy Electric Locomotive Ever Built. Equipped with four 270-h.p. gearless motors

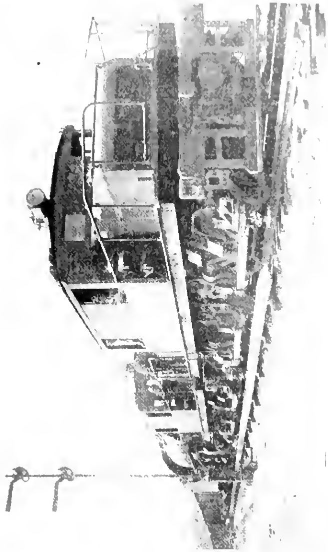


Fig. 4. Two of the Latest Type 100-ton Electric Locomotives Hauling Heavy Freight Train and Road Engine

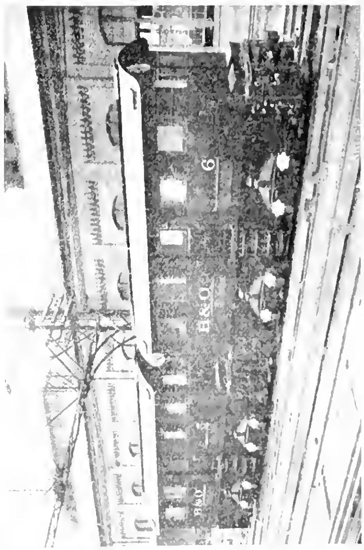


Fig. 5 Freight Locomotives, Eight-wheel, Rigid Base. Equipped with four 200-h.p. motors

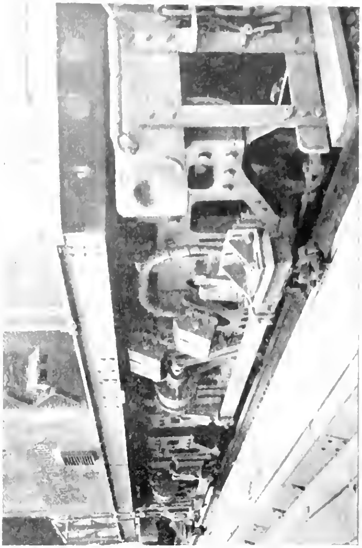


Fig. 6. Close View Showing Locomotive Shoe Rigging and Third Rail

Power Supply

Originally all power for the operation of the electrified section was supplied directly from a power plant built for that purpose and located at the western end of the zone. The generating station consisted of five 500-kw 700-volt direct-current generators direct-connected to tandem compound non-condensing Corliss engines. At the time of installation, in the early nineties, these were the largest direct-connected generators ever installed up to that time. To obtain more economical operating conditions as well as to improve the voltage on the line, a storage battery substation was subsequently installed near the Mt. Royal passenger station, one and three-quarter miles from the power house. A booster system of control was used which included a booster located in the power house, thus permitting a reduction of the generating voltage to 550 in order that current could be used for industrial purposes. This booster limited the power-house output to 900 kilowatts for traction purposes which with the battery was sufficient to handle one freight train of 1,600 tons weight including electric locomotive and one light passenger train simultaneously. This arrangement, however, was outgrown due to the increasing weight and number of trains, and it became necessary in 1909 to provide for a very material increase in power for traction purposes. After very careful consideration it was decided to purchase power from the local electric light and power company in the form of 3-phase, 13,000-volt, 25-cycle current, at which time a rotary converter substation was installed at Mt. Royal, in which three 1,000-kw., 650-volt synchronous converters with necessary auxiliaries were installed, sufficient space being provided for additional machines. The battery, which was of 3,200 ampere-hours capacity at the eight-hour rate, was retained for peak work and for minimizing the "demand" for purchased service.

Fig. 7. Mt. Royal Substation of the Baltimore & Ohio Railroad

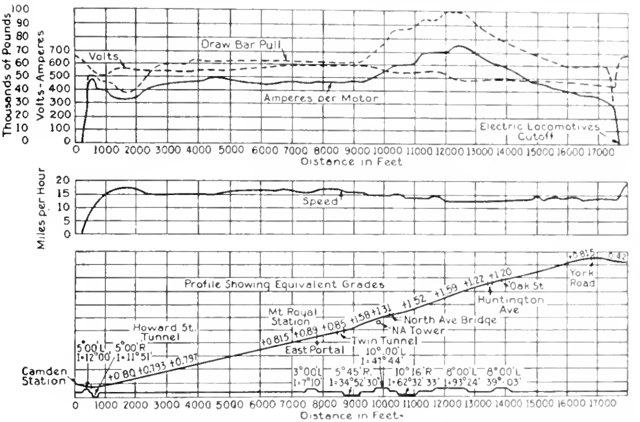
The power plant was abandoned and dismantled upon inaugurating purchased service through the Mt. Royal substation. In November, 1914, when purchased service was extended to cover all the electrical requirements of the railroad for lighting and power in Baltimore, the Mt. Royal battery was abandoned and dismantled, as by the extension of the use of electric service with consequent improvement in load factor, further operation of the battery was unnecessary and uneconomical. An additional 2,000-kw. rotary converter was installed about this time, thus providing sufficient capacity to handle simultaneously two freight trains each of gross trailing weight of 2,840 tons.

wheel through a spider and rubber driving cushions. After approximately a quarter of a century, direct-current gearless motors operating at 3,000 volts were decided upon for the passenger locomotives now used on the Coast Division of the Chicago, Milwaukee and St. Paul Railroad.

Operating Features

The service in the electrified zone is very similar to helper locomotive service except the road locomotives furnish no assistance. The ruling grade in the zone is 1.58 per cent eastbound while that of the remainder of the steam locomotive division to Philadelphia is but 0.8 per cent. This necessitates that the electric locomotives develop twice the tractive effort required of steam locomotives. On account of the shortness of the run steam locomotives are hauled through the zone with their trains. The electric locomotives return light as, on account of the grade, westbound traffic operates through the zone without requiring power from the steam locomotive except for starting.

The present maximum rating for freight trains handled over the Belt Line is about



Test No 7 Nov 5, 1913
Freight Train Locomotive No 4033
Electric Locomotives No 13 and 14
Weight of Train and Steam Locomotives 2452.5 Tons
Weight of Dynamometer Car 57.2 Tons
Total Weight Including Elec Locomotives 2709.7 Tons

	Camden To Mt Royal		Mt Royal To Oak St		Oak St. To York Rd		Camden To York Rd	
	Min	Sec.	Min	Sec.	Min	Sec.	Min	Sec.
Time (Min) (Sec)	6	58	4	40	3	8	14	46
Speed (M.P.H.)	13.7		12.9		11.9		13.1	
Draw Bar Pull	56300		81930		66500		67180	
Amp Per Motor	443		598		443		498	
Volts (Line)	563		540		468		538	
Watthours Per Ton Mi.							60.6	

Fig. 8. Dynamometer Test Curves and Data

Locomotives

Three types of locomotives have been used. The original locomotives weighing 96 tons were designated as Class LE-1. The second lot of locomotives weighing 80 tons were designated as Class LE-2 and were designed exclusively for freight service. The last lot of locomotives purchased weighed approximately 100 tons and are designated as OE-1 and OE-2.

It is very interesting in this connection to recall that the three original Baltimore and Ohio electric locomotives were equipped with gearless motors, i.e., the armatures were mounted directly on the main driving axle, power being communicated to the driving

TABLE I

COST OF OPERATION AND MAINTENANCE OF ELECTRIC LOCOMOTIVE SERVICE ON B. & O. R. R.

	1910		1911		1912		1913	
	Per 1000 Ton Miles	Per 100 Locomotive Miles	Per 1000 Ton Miles	Per 100 Locomotive Miles	Per 1000 Ton Miles	Per 100 Locomotive Miles	Per 1000 Ton Miles	Per 100 Locomotive Miles
Trainmen's wages	$0.34	$9.15	$0.336	$8.43	$0.328	$9.40	$0.325	$9.68
Power	1.46	39.10	1.320	33.20	1.060	30.30	1.155	34.40
Third rail and feeder maintenance	0.093	7.85	0.109	2.74	0.230	6.58	0.205	6.12
Oil and waste	0.007	0.18	0.007	0.202	0.006	0.18	0.007	0.21
Misc. supplies	0.002	0.05	0.002	0.048	0.001	0.02	0.002	0.06
Inspection, repairs, cleaning	0.203	5.44	0.201	5.05	0.197	5.64	0.213	6.35
Total	$2.305	$61.77	$1.975	$49.66	$1.822	$52.12	$1.907	$56.80

	1914		1915		1916*		1920*	
	Per 1000 Ton Miles	Per 100 Locomotive Miles	Per 1000 Ton Miles	Per 100 Locomotive Miles	Per 1000 Ton Miles	Per 100 Locomotive Miles	Per 1000 Ton Miles	Per 100 Locomotive Miles
Trainmen's wages	$0.327	$9.67	$0.308	$9.50	$0.252	$7.52	....	$19.30
Power	1.215	35.80	1.015	31.20	.800	24.40	....	43.50
Third rail and feeder maintenance	0.142	4.18	0.137	4.20	0.117	3.58	....	8.13
Oil and waste	0.007	0.21	0.007	0.20	0.006	0.17	....	0.32
Misc. supplies	0.022	0.06	0.001	0.03	0.001	0.02	....	0.08
Inspection, repairs, cleaning	0.178	5.27	0.170	5.24	0.183	5.42	....	13.60
Total	$1.871	$55.49	$1.638	$50.37	$1.359	$41.11	....	$84.93

* Calendar year.

TABLE II

TRAFFIC DATA ON BELT LINE ELECTRIFICATION OF B. & O. R. R.

	1910	1911	1912	1913
Fiscal Year Ending June 30				
Number of passenger trains handled	7,471	6,963	5,784	6,049
Number of freight trains handled	10,456	10,001	7,164	7,535
Mileage electric locomotives	183,493	213,366	192,774	191,124
Ton-miles, including electric locomotives	49,224,569	53,652,332	55,286,817	57,099,821
Gross watt-hours per ton-mile	109	92	93	118
Cost of current per kw-hr. at d-c. bus	$0.0185	$0.0182	$0.0143	$0.015

	1914	1915	1916*	1920*
Fiscal Year Ending June 30				
Number of passenger trains handled	6,211	6,274	......	......
Number of freight trains handled	7,236	7,028	......	......
Mileage electric locomotives	183,434	190,000	233,750	228,402
Ton-miles, including electric locomotives	54,169,376	58,539,501	70,571,450	......
Gross watt-hours per ton-mile	103	101	94.1	......
Cost of current per kw-hr. at d-c. bus	$0.0139	$0.0126	$0.0135	$0.0245

* Calendar year.

TABLE III

BALTIMORE AND OHIO ELECTRIC LOCOMOTIVES

Serial numbers	6 to 9	11 and 12	13 and 14
Number in service	1	2	2
Year placed in service	1903-06	1910	1912
Class of service	Freight	Pass. and Frt.	Pass. and Frt.
System of traction	D-C.	D-C.	D-C.
Contact conductor: Voltage	600	600	600
Type	3rd rail	3rd rail	3rd rail
Classification	0-8-0	0-4-4-0	0-4-4-0
Driving wheels: No.	8	8	8
Diam.	42 in.	50 in.	50 in.
Truck wheels: No.	0	0	0
Diam.	0	0	0
Weights: Total	160,000	185,000	200,000
On drivers	160,000	185,000	200,000
Per driving axle	40,000	46,250	50,000
Mechanical parts	116,000	119,000	135,000
Electrical parts	44,000	66,000	65,000
Dimensions: Length over all	29 ft. 7 in.	39 ft. 6 in.	39 ft. 6 in.
Width over all	9 ft. 2 in.	10 ft. 2½ in.	10 ft. 2½ in.
Height rail to highest point	13 ft. 8 in.	14 ft. 5 in.	14 ft. 5 in.
Wheel base: Rigid	14 ft. 6¾ in.	9 ft. 6 in.	9 ft. 6 in.
Total	14 ft. 6¾ in.	27 ft. 6 in.	27 ft. 6 in.
Motors: Number	4	4	4
Type	G.E.65B	G.E.209	G.E.209
Horse power—One-hour rating with forced ventilation	200*	275	275
Method of drive	Geared	Geared	Geared
Gear ratio	81:19	78:21	78:24
Tractive effort: At one-hour rating with forced ventilation	36,000	26,000	26,000
At continuous rating with forced ventilation	......	13,000	13,000
Maximum starting	40,000	46,000	50,000
Horse power of locomotive with forced ventilation:			
One hour rating	800*	1,100	1,100
Continuous rating	....	660	660
Speed: m.p.h.: Hour rating	8.0	16.6	16.6
Continuous rating	....	19.5	19.5
Maximum safe	....	45	45

* Natural ventilation. This motor not designed for forced ventilation.

TABLE IV

COST OF MAINTENANCE OF ELECTRIC LOCOMOTIVES OF B. & O. R. R.

Class	LE-2		OE-1 and OE-2	
No. in service	4		4	
Serial numbers	6–9		11–14	
Year built	3 in 1903 and 1 in 1906		Two in 1910 and two in 1912	
Year	Mileage	Cost per Loco. Mile	Mileage	Cost per Loco. Mile
1909	126,258	$0.029		
1910	138,098	0.041	42,110	$0.029
1911	129,146	0.044	61,112	0.051
1912	92,550	0.063	91,430	0.032
1913	87,556	0.054	98,816	0.071
1914	78,432	0.051	106,091	0.055
1915	93,444	0.046	113,312	0.049
1916	107,464	0.051	129,748	0.067
1917	95,458	0.052	136,344	0.046
1918	91,392	0.077	133,420	0.074
1919	61,916	0.181	145,832	0.091
1920	80,298	0.154	148,104	0.058

2,250 actual tons including steam locomotive weighing approximately 230 tons. Two class OE-1 or OE-2 locomotives haul these trains on the maximum grade at speed of 15 miles per hour which is nearly twice the speed obtained with Mallet steam locomotives on corresponding grades with full loading.

As of interest in this connection Fig. 8 shows the results of a dynamometer test with two class OE-2 electric locomotives hauling a 2,450-ton train over the Belt Line, the total weight of train including the electric locomotives being 2,709.7 tons. These curves are typical of freight train performance except the weight is somewhat above normal train weights.

Traffic

Traffic at present consists of handling about 33 trains eastbound daily of which there are seven through passenger trains for the east and one or two locals, the remainder being eastbound freight trains. On special occasions a considerably greater number of eastbound trains may be handled within a 24-hour period. Table II presents traffic data to show by years the number of trains handled, locomotive mileage, ton-miles, kilowatt-hours consumed, etc.

Operating Statistics

Tables I, II, and IV include data of the principal operating statistics, also of the cost of maintaining electric locomotives, etc.

A Transition Period in Radio Communication

PART II

By A. F. Van Dyck

Radio Engineering Department, General Electric Company

The successive inventions of devices and innovations in practice that have been made to perfect radio communication may be grouped into five epochs, the last being that which we are entering today. The developments that are bringing about the present transition were detailed in Part I of this article. The present installment outlines the influence which recent devices are bringing to bear on the present status of radio and predicts what effect this will probably have on the practice of the art in the near future.—Editor.

In the previous installment of this article the recent developments in radio were listed and described. Consideration will now be given to their effects upon the several divisions of radio communication, the conditions in each as they stand today, and the possibilities when the new epoch is firmly established. First, in the division of long-distance communication, it will be found that of the seven stations in this country which may be rated high-power stations, all employ the continuous-wave system; four are equipped or are being equipped with radio-frequency alternators, and the remaining ones are equipped with arc oscillators. Likewise, all but two of the foreign stations working with this country are now of the sustained-wave type. That is, continuous-wave systems are already practically universal in the high-power field. It is to be noted that the modern high-power radio station approaches closely in nature to the electric power station. The equipment of an alternator station is reduced to standard power machinery, the radio alternator, and simple radio-frequency transformers and reactors. The elimination of such apparatus as spark gaps, high-tension condensers, together with the large uncertain transient potentials involved in their use, results in a large increase in the degree of reliability of the station as an operating unit.

The extent of this development of the transmitting station is shown by the plan under which the Radio Corporation of America is constructing a new station on Long Island. In this station there will be concentrated equipment which will be equivalent to perhaps eight stations of previous types. The antennas and the generating equipment will be so arranged that it will be possible to utilize on any one of the foreign circuits as much generator power and radiation area as may be required to effect communication under all probable combinations of traffic demand and atmospheric condition. As has been pointed out by Mr. Alexanderson,* the economical factors of best utilization of plant investment and operating force are practically the same in the radio station as in the electric power station.

The same centralization of equipment and operation of receiving stations will simulta-

* Paper presented before Institute of Radio Engineers and New York Electrical Society, November, 1920.

neously come about, and the great progress in reception methods, which has been made despite the difficulties previously mentioned and which has already reduced the number of service interruptions to remarkably few, can be expected soon to eliminate them altogether. Anyone familiar with the battles between signals and strays, who hears the adjustment of present day receiving apparatus result in the decrease of strays and the issuance of clear signals, knows that the most difficult radio problem is nearing complete solution.

It is well to note the great importance of long-distance radio communication. We have been accustomed to consider radio as a convenient means of communication between ship and shore, aircraft to ground, and possibly between land points where wire installation or maintenance was difficult, but we have not had cause previously to consider it as a factor in economics or world politics. We do know that, in the past, the introduction of improved communication or means of disseminating information has resulted in a closer unity of thought and purpose among the parties affected. The familiar examples of the railroad, the telegraph and telephone, and the newspaper are sufficient to mention.

Likewise, long-distance radio is certain to have effect on international relations. The cables, which have connected countries in a limited way, have permitted highly restricted communication only. The cable has two ends and no middle; the radio [illegible] has an infinite number of both ends and middle. In addition to this characteristic difference, radio has the advantage of permitting higher speeds of transmission and also distortionless telephony, both of which so far have been impossible of accomplishment with cables. These fundamental differences are mentioned because it is necessary to consider them to understand why international radio communication will have more effect than cable communication has had in the past. An example of the influence of communication facilities is afforded by the difference in our knowledge of the nations of Europe and those of South America. It is true that other factors cause some of this difference, but we appreciate how little we know of the South American countries, and can see what would be added by a possibility of obtaining plentiful news of current events and opinions. If we imagine the state of radio communication a few years hence, with central stations giving both telegraph and telephone service and working with high-speed automatic transmission and reception directly into our cities which are large traffic centers, it is not difficult to realize that we shall come into closer relation with other nations. And of course closer relations mean a better understanding, a better realization of the commonwealth of nations, and to the same degree that this transpires will come improbability of causes for international war. Long-distance com-

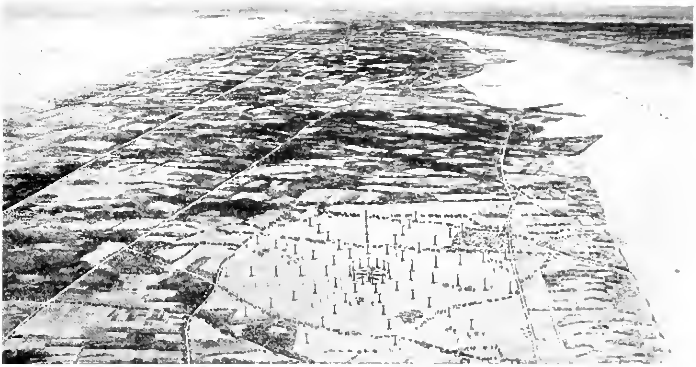


Fig. 1. Radio Central Station Now Being Erected on Long Island by the Radio Corporation of America
This station will communicate with several European and South American stations simultaneously, and the first spoke is expected to be in operation by October 1st

munication will therefore work for the betterment of world commerce, world polities, and world brotherhood. The present transition period is seeing the inauguration of this work of radio.

In the field of short-distance communication, we find that the recent improvements are causing radical changes and additions to established radio practice. This is more noticeable in the short-distance field than in the long-distance, because short-distance work was an established and accepted service more than five years ago while long-distance radio was still more or less experimental in nature. It is therefore more difficult to accomplish the apparatus innovations for short-distance work. However, the improvements are great enough so that commercial pressure is causing the introduction of the known improvements as rapidly as is economically possible.

In short-distance commercial reception, there is coming about the introduction of vacuum-tube detectors and amplifiers as the chief departure from established practice. The addition of these devices means first, a better reliability of operation, partly because of greater stability of this form of detector and partly because signals can be amplified to better readability, and second, a greater distance range of communication. Greater stability is valuable because detectors previously used required frequent adjustment to maintain a good operating condition, and many a call has been missed and many a message lost for this reason. Greater range is desirable in some classes of ship service to permit working with shore stations nearer to the destination of messages. The value of this is seen when one considers the case of the large transatlantic liners, whose present reliable operating range of 300 to 500 miles will shortly be closer to 1000 miles. This distance is equivalent to two days out of port and means that practically all traffic of the ship can be handled directly to the port of arrival or departure, which in this country, at least, is the destination of the greatest part of the radio traffic. If traffic is sent directly to destination, or close to it, time and expense of relay over wire lines can be saved.

Fig. 2. Radio Power House at Marion, Mass. A few of the fourteen masts which support the antenna system are visible behind the power house

Short-distance transmitters are undergoing a change more sweeping than any other radio apparatus. Until now, these transmitters have been of the spark type, that is, the necessary radio frequency energy has been obtained from the discharge of condensers through spark gaps. This method has been the most reliable and generally most suitable form of transmitter for short distances. It had been developed to the limit of its possibilities, but still retained the inherent disadvantage of being an interrupted source of energy rather than a continuous one. The new method, using the vacuum tube, produces continuous voltage or continuous waves, thereby giving a more satisfactory transmitter as well as permitting the use of more efficient methods of reception. There are several advantages to be derived from the change to continuous-wave transmitters. The chief one is less interference among stations in a given area carrying on simultaneous communication. This is important because at present, in congested sections, difficulty is experienced with spark transmitters in carrying on several simultaneous communications. The use of continuous waves will not eliminate this difficulty by any means, but certainly will reduce it. Another main advantage comes from the these more selective transmitters highly selective receivers are being developed, and so we shall have the possibility of an increase in the number of communications which can be carried on in a given area. This is the fundamental problem in radio, to obtain such methods that the number of stations permissible in any area can be made whatever is desired. With radio by any method now known, it is probable that the possible density of stations can not approach that of wire stations, but also there is the condition that it will probably not be desired to accomplish this extreme limit.

A result of great importance, coming from the use of continuous-wave transmission, is

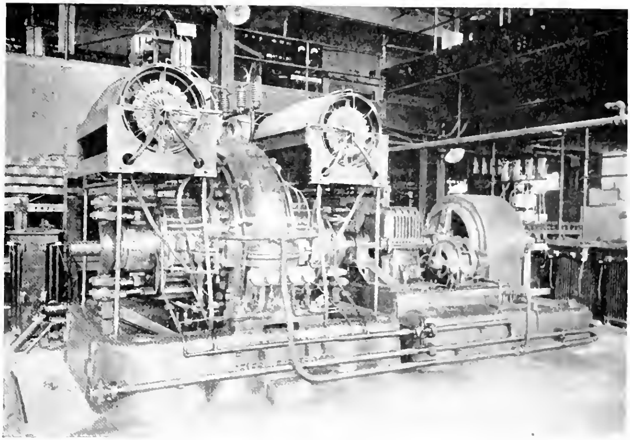


Fig. 3. Alexanderson Alternator Installed in High Power Radio Station

fact that the vacuum-tube transmitter is applicable to radio telephony as well as telegraphy. Tube transmitters have already been used in service to a considerable extent, mostly confined to short-distance work, chiefly military, and for new applications such as aircraft, artillery units, and first line of infantry communications. These applications are mostly served by sets with outputs of not over 50 watts. The introduction into commercial communication service of vacuum-tube sets, replacing the present spark sets, will take a longer time than has their induction into military service. Judging from past experience, it will be four or five years before tube sets are universally used. Along with the development of radio-telephony. A review of the present uses of radio makes it appear that the field for radio-telephony may be limited, but it is well to reflect on the history of wire telephony, and with this in mind it will appear reasonable and probable that telephonic radio communication will in time outstrip the radio telegraph in usefulness.

It is interesting to realize that the vain efforts of the early investigators have at last resulted in successful telephony, and that success has come so suddenly that it is somewhat difficult to appreciate it. Even in the early days of spark transmitters, the pioneers were searching for means whereby telephony could be accomplished. The use of spark frequencies above audibility was the only possibility, and this was not a satisfactory method. Then De Forest with the Poulsen arc, and Fessenden with the alternator, marked the next steps of progress. The first completely successful method, however, resulted from the vacuum-tube discoveries. This method is completely successful because it is workable with any power, and control of its output by speech energy is easily and perfectly obtained.

The present applications of radio telephony, in general, are the following:

(a) Ship to ship
(b) Ship to shore*
(c) Ship to land wire telephone system
(d) Between fixed land stations
(e) Aircraft to fixed stations
(f) Between mobile land stations.

The first two classes of telephone service will be used chiefly by ships' officers, port officials, etc., for communication in connection with the business of the ship, and will be of little use to passengers. Ship to land telephone line communication is the service which will have greatest public usefulness, since this in effect transforms every telephone installation in the country into a radio station able to communicate with ships at sea. Doubtless, in a few years, it will be possible to extend this service to transoceanic distances, so that any telephone in this country may be linked to any one in a foreign country. One feature of radio telephony which will militate against it for a time is its lack of secrecy. This has not been felt seriously in radio telegraphy, since confidential communications could be coded easily. This is not easily possible in telephony, so that radio telephony will not be fully utilized until technical advance provides secrecy. Fairly satisfactory methods for accomplishing this are known already, and when thoroughly worked out the feature of secrecy will be added.

Fixed land station telephony will be useful between isolated points not connected by wire lines, and it is probable that considerable use of this service will be made in the central and far west sections of this country, particularly in oil, mining, and forestry regions.

Aircraft to fixed station telephony will probably be useful mainly for navigational purposes. Telephony is particularly advantageous to aircraft because there is no necessity for carrying an expert telegraph operator.

* See article "Marine Uses of Radio," by A. Stein, GENERAL ELECTRIC REVIEW, February, 1921.

Mobile land station telephony may become important in various applications in time, but avoiding any stretching of the imagination we can see one application which will come about early in the new epoch; namely, telephonic communication with moving trains

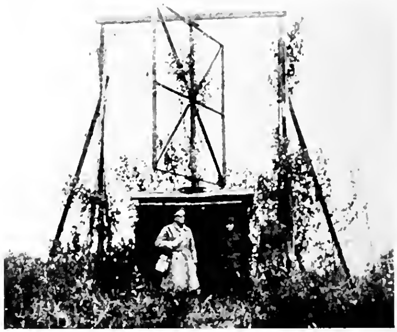


Fig. 4. Direction Finding Radio Station with Camouflage Protection as Employed for Military Purposes in France

and perhaps safety control of trains through radio means, in addition to communication. This will have an important effect on the dispatching of trains as well as afford communication conveniences to passengers.

It is to be noted especially that the introduction of telephony, and the consequent possibility of eliminating the expert telegraph operator in many classes of service will require a greater refinement of apparatus design than has been necessary in the past. Radio apparatus is unique among electrical equipment in that it involves the use of many devices of the nature of laboratory instruments, and yet is submitted to service conditions and operation which equal in severity that which is given to ordinary electrical apparatus of more robust nature. It must be the object of the designer of radio apparatus under the new conditions to create product satisfactory in this important particular. Much advantage can be gained from the mistakes and the successes of the past epoch apparatus, but even the best of this must be improved upon to give reliable service without the attention of expert attendants, which has always been available in the past.

Some of the developments previously described have led to the successful introduction into service of a new use of radio which will be very important in the new epoch. This use, direction finding, is a departure from the field of pure communication, and well illustrates the fact that radio is branching out into a more general usefulness than has been expected. The direction finder is a device for determining the direction from which radio signals are received, and is now practicable as a result of the improvement in sensitiveness of receiving apparatus. It has long been known that antennas of certain forms were highly directive in receptive ability, but these forms were such that sufficient energy could not be collected by them to operate the detecting apparatus then known, and in consequence, the distance over which results were obtainable was not sufficient to make the device useful. Now, however, with amplifying equipment, it is possible to receive signals on these highly directional antennas over sufficient distances.

A modern addition toward refinement of the device consists of means for determining not only the line of direction along which the radio signal is travelling, but also which way from the receiving station the transmitter is located. The uses of the direction finder at present are two in number; one, which we trust will be of lesser importance in the future, is for the location of enemy radio stations in war. It is to be noted that a proper system of direction finding stations will determine not only the direction from which the radio signals are received, but by methods of triangulation will permit the sending station actually to be located. The more important use of the direction finder is for assistance to navigation of ships. Direction finding stations have been erected along the coasts, which, upon request from a ship, will make determination of the ship's position and inform the ship by radio telegraph. Naturally, mariners were cautious at first in accepting this strange method, but are rapidly learning to trust the accuracy of this work. When radio direction finding has become an established part of the practice of navigation, one of the greatest hazards will have been removed, and navigation near coasts, at least, will be much simplified. The eventual value of the direction finder to navigation is inestimable, and present practice of navigation may be greatly changed by it. The direction finder is similarly adaptable to aircraft navigation where its assistance is even more advantageous, since aircraft meet adverse visual conditions and uncharted currents more frequently than sea vessels.

The new radio devices which have been mentioned are of kinds which are useful in other electrical fields. On account of this fact, radio practice is beginning to have influence on general practice, and, on the other hand, radio in the new epoch will be assimilated in the electrical family, losing the specialization and distinctiveness which have characterized it in its past epochs. Some of the applications of radio, or of apparatus first developed for radio purposes are as follows:

Telautomatics, or the control of devices at a distance; for example, torpedoes, mines, ships, etc.

Sound signalling, sound detection; for example, the location of distant aircraft, the use of the loud-speaking telephone for increasing the voice range of public speakers.

Microphonic work in general, including physiological, chemical, and physical studies.

Wired wireless, or the use of radio-frequency currents on wire lines for the purpose of obtaining the multiplexing possibilities of resonant tuning.

It seems certain that these new fields of usefulness, in addition to the great improvements in pure communication, will cause the fifth epoch in radio to stand out in importance over any which have gone before. It would seem that radio, after its score of years, has reached maturity and is ready to take its place among the established arts.

Methods for the Production and Measurement of High Vacua

PART XI. TEMPERATURE DROP, SLIP, AND CONCENTRATION DROP IN GASES AT LOW PRESSURES

By Saul Dushman

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This instalment, which completes the series of articles on the subject of high vacua, contains a discussion of certain low-pressure phenomena which are of importance from the point of view of Langmuir's theory of the unimolecular layer. A summary is given of the topics discussed in the previous instalments of the series, and an appendix has been added which contains tables of formulas and data which ought to prove useful in connection with investigations at low pressures.—Editor.

Reflection of Molecules

In discussing Langmuir's theory of adsorption it has been stated as the fundamental postulate of this theory that practically all atoms or molecules when striking a surface *condense, no matter what the temperature of the surface may be*. It is true, of course, that the condensed atoms may re-evaporate very rapidly especially if the surface is at a high temperature. But the point is that there is practically little or no specular reflection of molecules striking any surface. All of Langmuir's experimental observations and results obtained on adsorption by other investigators are in accord with this point of view. In the present section we shall discuss certain phenomena in gases at low pressures which may be regarded as supporting the fundamental postulate stated above.[1] Furthermore, these phenomena illustrate in a striking manner the radical differences between the properties of gases as observed at ordinary pressures and those observed at low pressures.

Coefficient of "Slip" in Gases at Low Pressures

In discussing the theory of viscosity manometers[2] it was pointed out that at low pressures there is distinct evidence of a slipping of gas molecules over planes. Denoting the coefficient of slip by δ, it can be shown that the amount of momentum, B, transferred from a plane moving with velocity u parallel to a stationary plane situated at a distance d is given by the relation

$$B=\frac{\eta u}{d+2\delta} \qquad (1)$$

where η is the coefficient of viscosity as determined at higher pressures. Thus, owing to this slip there is an apparent increase in the thickness of the gas layer between the two surfaces, this increase amounting to δ for each surface. It was shown by Kundt and Warburg in their early investigations on this subject[3] that δ is of approximately the same order of magnitude as the mean free path. At a pressure of 1 bar, the mean free path for ordinary gases is about 10 cm.,[4] and since the mean free path varies inversely as the pressure, it is evident that at very low pressures, d, the distance between the plates is negligible compared to δ. Consequently, equation (1) assumes the simple form

$$B=\frac{\eta u}{2\delta} \qquad (2)$$

We thus see a radical difference here between the viscosity effects exerted by a gas at high and low pressures, respectively. At ordinary pressures, the value of B is independent of the pressure, whereas at very low pressures it varies inversely as the mean free path and therefore directly as the pressure. In other words, at low pressures the amount of momentum transferred per unit area decreases enormously as compared with that observed at ordinary pressures.

Physically this is accounted for, as has been pointed out in a previous connection, by the fact that at very low pressures the molecules can travel from one surface to the other without mutual collisions. We have here the condition designated by Knudsen as that of "molecular flow."

Knudsen[5], Timiriazeff[6] and Baule[7] have attempted to derive a relation between δ

[1] Langmuir, "The Evaporation, Condensation and Reflection of Molecules and the Mechanism of Adsorption." Phys. Rev. *8*, 149 (1916).
[2] Part IV of this series. General Electric Review *23*, 735 (1920).
[3] Poynting and Thomson, "Properties of Matter," p. 220.
[4] See Part I of this series, General Electric Review *23*, 498 (1920), for table of mean free paths.
[5] M. Knudsen, Ann. Phys. *28*, 75 (1908); *35*, 389 (1911).
[6] A. Timiriazeff, Ann. Phys. *40*, 971 (1913).
[7] B. Baule, Ann. Phys. *44*, 145 (1914).

and the mean free path (L). In order to compare their results we shall write

$$\delta = bL \tag{3}$$

where b is a constant whose value may be slightly greater or less than unity.

According to the kinetic theory of gases

$$\eta = \tfrac{1}{3}\rho\Omega L \tag{4}$$

where ρ = density, Ω = average (arithmetical) velocity, and the factor $\tfrac{1}{3}$ has been taken as the average of the values 0.31 used by Meyer and 0.35 used by Boltzmann.

Substituting for ρ and Ω the relations

$$\rho = \frac{Mp}{RT}$$

$$\Omega = \sqrt{\frac{8RT}{\pi M}}$$

we therefore obtain the relation

$$L = \frac{3}{4} \cdot \frac{\eta}{p} \sqrt{\frac{2\pi RT}{M}} \tag{5}$$

and consequently

$$\delta = \frac{3b}{4} \cdot \frac{\eta}{p} \sqrt{\frac{2\pi RT}{M}} \tag{6}$$

All the investigators mentioned above are agreed in the conclusion that the exact value of b must depend upon the ratio between the number of molecules reflected according to the laws of specular reflection and the number actually striking the surface. Knudsen assumes that in general this ratio is practically zero. In other words, the momentum of all the molecules striking a surface is practically completely transferred to this surface. On this basis he derives the relation

$$b = \frac{32}{9\pi} \cdot \frac{C_1}{C_2} \tag{7}$$

and determines experimentally the value of C_1/C_2 to be 0.81.

Substituting this result in equation (3), we obtain the relation

$$\delta = 0.917\, L \tag{8}$$

Timiriazeff, on the other hand, assumes that the amount of reflection in viscosity effects is the same as that observed in heat conduction at low pressures (see below), and derives the relation

$$\delta = \frac{2-f}{f} \cdot \frac{2}{3} L \tag{9}$$

where f is the so-called "accommodation coefficient" for heat transfer in gases.

If we assume $f = 1$, as Knudsen does, we obtain the relation

$$\delta = 0.67\, L \tag{10}$$

There is evident here a difference between the deductions obtained by Knudsen and Timiriazeff.

Baule, who has discussed the subject in considerable detail, disagrees with the assumption made by Timiriazeff that f has the same value for both viscosity and heat conduction. The relation derived by him may be written in the simplified form

$$\delta = \frac{1+s}{1-s} \cdot \frac{2}{3} L \tag{11}$$

where s is a complicated function of the dimensions of the molecules in the gas and those constituting the surface. The value of this constant may vary from 0 to 0.5; consequently the value of b lies between 0.67 and 1.0.

The actual experimental data on this subject are not sufficiently exact to make it possible to reach any certain conclusions. From his experiments on the flow of gases at low pressures through capillary tubes, Knudsen concluded[5] that in the case of hydrogen there cannot be a specular reflection amounting to more than about one per cent. On the other hand, "Millikan[8] has calculated the coefficient of slip from his measurements on the fall of small spheres and has concluded that the slip in air is about 10 per cent, and in hydrogen about 8 per cent greater than would be expected according to Knudsen's assumption regarding the absence of specular reflection."

Gaede[9] has made the interesting observation that at pressures ranging from 0.001 mm. to 20 mm. the amount of gas which flows through a narrow tube is *less* than that calculated by Knudsen on his theory. This would correspond to a *negative* value of the coefficient of slip, and Gaede therefore concludes from his measurements that a certain fraction of the incident molecules tend to return after collision in the direction from which they came.

"Temperature Drop" at a Surface in Gases at Low Pressures

In analogy with the existence of slip in viscosity effects at low pressures there has been observed in the case of heat conduction at low pressures between two surfaces the existence of a temperature drop at each surface corresponding to a fictitious distance γ.

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[8] Quoted by Langmuir, Phys. Rev. *8*, 155 (1916).
[9] Ann. Phys. *41*, 289 (1913).

This constant is designated as the *coefficient of discontinuity of temperature*. The analogy between this coefficient and that of slip is seen from the relation for the heat transferred per unit area per unit time, which assumes the form

$$\frac{Q}{T_2 - T_1} = \frac{\kappa}{d + 2\gamma} \tag{12}$$

where κ is the heat conductivity. The similarity between this equation and equation (1) is evident.

The existence of this effect, although predicted by Kundt and Warburg as a result of their investigations on the coefficient of slip, was first observed and investigated theoretically by Smoluchowski[10] in 1898.

Assuming, as Maxwell did in his treatment of slip, that the fraction f of the incident molecules is absorbed and evaporated again with a velocity distribution corresponding to that in the still gas at the temperature of the solid, while the fraction $1-f$ is reflected, Smoluchowski derived a relation which may be written in the form

$$\gamma = \frac{2-f}{f} \cdot \frac{5}{4} L^* \tag{13}$$

Assuming that f in heat transfer has the same value as in the case of slip, it follows by comparing with equation (9) that

$$\gamma = \frac{15}{8} \delta \tag{14}$$

It will be observed that for $f=1$, equation (13) becomes

$$\gamma = 1.25L$$

Actually it was observed that between glass surfaces in air, $\gamma = 1.70L$ and in hydrogen, $\gamma = 6.96\,L$. According to equation (13) this would correspond to the values 0.85 and 0.305 for f in air and hydrogen respectively. That is, in the case of hydrogen, 69.5 per cent of the molecules striking a heated glass surface would suffer specular reflection.

Smoluchowski also suggested another method of considering this phenomenon. When molecules with kinetic energy corresponding to a temperature T_1 strike a surface at a higher temperature T_2, the molecules leaving this surface have this temperature only if there is complete equalization of temperature during the act of impact on the plate. If this is not the case, the molecules leaving the surface have a temperature T intermediate between T_1 and T_2 such that

$$T - T_1 = \alpha (T_2 - T_1)$$

or

$$T = \alpha T_2 + (1-\alpha) T_1 \tag{15}$$

where α is a number less than unity, which has been designated as the "accommodation coefficient" by Knudsen.

At very low pressures, where the mean free path is greater than the distance between the plates, it can be shown that the amount of heat transferred per unit time per unit area and per unit difference of temperature between the plates is

$$Q = \frac{\alpha}{2-\alpha} \cdot E \cdot p \tag{16}$$

where E denotes the molecular heat conductivity at the temperature T.

Since at these pressures

$$Q = \frac{\kappa}{2\gamma}$$

it follows that

$$\gamma = \frac{\kappa}{p.E} \cdot \frac{2-\alpha}{\alpha} \tag{17}$$

For a monatomic gas

$$\frac{\kappa}{p.E} = 2.5\,L \tag{18a†}$$

For a diatomic gas

$$\frac{\kappa}{p.E} = 1.83\,L \tag{18b†}$$

Hence for monatomic gases

$$\gamma = \frac{2-\alpha}{\alpha}(2.5\,L)$$

and for diatomic gases

$$\gamma = \frac{2-\alpha}{\alpha}(1.83\,L)$$

For $\alpha = 1$ we must therefore obtain values of γ which vary from $0.915\,L$ in case of diatomic gases to $1.25\,L$ in that of monatomic gases.

Baule[11] who, as mentioned above, has critically discussed the whole problem of slip and temperature drop, has pointed out that it does not at all follow that the accommodation coefficient should be the same for both slip and heat conduction. Instead of the

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* Using the factor 0.31 in Meyer's equation for L in terms of η, Smoluchowski derives a relation with the coefficient $15/4\pi$ in place of $5/4$.

† These relations have been calculated from the equations given by Baule for E and the relations derived for κ in the kinetic theory of gases (See GENERAL ELECTRIC REVIEW, 1915, pp. 1046-7) using the relations

$$\kappa = B\eta C; \text{ and } \eta = (1/3)\ \rho\Omega L.$$

For monatomic gases $B = 2.50$ and for diatomic, $B = 1.9$.

[10] Phil. Mag. *46*, 192 (1898), Ann. Phys. *35*, 983 (1911).

[11] For a summary of Baule's discussion, the reader may consult Langmuir's paper, Phys. Rev. *8*, 149 (1916).

value $\frac{\delta}{\gamma} = \frac{8}{15}$ as deduced by Smoluchowski, he concludes that $\frac{\delta}{\gamma}$ must vary with the nature of the gas and that of the surface. For the case of a nickel surface he calculates for air, carbon dioxide and hydrogen, the values 8/13, 8/13, and 8/80, respectively. These values are in substantial agreement with the experimentally observed results.

Langmuir[11] has adopted Baule's theory as a starting point but points out that the latter has failed in his arguments to take into account the existence of attractive (and repulsive) forces between the atoms on the surface and the colliding molecules. The existence of these forces would tend to lessen the velocity of molecules after collision and thus modify to a certain extent the values derived by Baule from theoretical considerations, and the conclusion is arrived at that the probability of any considerable amount of specular reflection is extremely small except in such a case as that of hydrogen.

Experimentally it has been found that in the latter case the coefficient of accommodation for heat transfer is only about 0.19. This is lower than that observed in any other case, and Langmuir has suggested various reasons for this exceptionally low value. On the whole the experimental work on temperature drop leads to the conclusion that the amount of specular reflection in heat transfer is ordinarily quite negligible and does not exceed a few per cent.

Recent Experiments of Wood and Knudsen on Condensation

Some more recent experimental observations made by R. W. Wood[12] and M. Knudsen[13] have been interpreted by these investigators as indicating that under certain conditions there may be considerable reflection of molecules at surfaces upon which they impinge. In Wood's experiments a stream of cadmium vapor in a well exhausted bulb was allowed to strike a glass surface at different temperatures. No visible deposit was observed unless the glass was held at a temperature below about −90 deg. C. On the other hand, once a deposit was started by cooling the glass at that spot with liquid air, the deposition of cadmium continued even after the deposit was warmed to room temperature.

From these and similar observations Wood concluded that while cadmium atoms condense on a cadmium surface at any temperature, they condense on glass only if the temperature is below about −90 deg. C. At higher temperatures all the atoms are reflected.

Similar observations have been made by Knudsen and still more recently by J. Weyssenhoff.[14] Knudsen experimented with mercury vapor and observed that at temperatures above −130 deg. C. most of the molecules impinging on a glass surface were apparently reflected. With other vapors a similar "critical temperature" was observed above which no condensation occurred. In the case of NH_4Cl, this critical change occurred at −183 deg. C., in that of copper at temperatures varying between 350 deg. and 575 deg. C., while in the case of zinc, cadmium and magnesium, the critical range extended between −183 deg. and −78 deg. C. All these observations held true only for a glass surface. On the other hand mercury atoms condensed on a mercury surface at all temperatures. This latter observation had been made by Knudsen in a previous investigation,[15] and in fact he had applied the relation

$$m = p\sqrt{\frac{M}{2\pi RT}}$$

to determine the vapor tension of mercury at extremely low temperatures from the rate of evaporation (m). As has been pointed out in a previous connection the application of this equation involves the assumption that there is no reflection of atoms of the vapor striking the surface from which evaporation is occurring.

Weyssenhoff carried out some experiments in order to determine the amount of reflection of mercury atoms striking surfaces of gold and iron. While no absolute determinations of the amount of reflection were obtained, he concludes from his experiments that at −100 deg. C., the reflection from gold is 5 to 10 times less than that from iron.

These observations have been interpreted by these investigators as indicating that at some temperature the accommodation coefficient for condensation changes very rapidly from zero to unity. Langmuir has, however, repeated Wood's experiments[16] and concludes from his observations that this deduction is not justifiable.

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12 Phil. Mag. *30*, 300 (1915); *32*, 364 (1916).
13 Ann. Phys. *50*, 472 (1916).
14 Ann. Phys. *58*, 505 (1919).
15 Ann. Phys. *48*, 1113 (1915).
16 Proc. Nat. Acad. Sciences *3*, 141 (1917).

In his experiments, Langmuir used cadmium vapor in a well exhausted bulb and investigated the effect of cooling a portion of the glass surface to different temperatures. He finds that "traces of residual gas may prevent the growth of the deposit, particularly in those places which have been most effectively cooled. This is probably due to the adsorption of the gas by the cooled metal deposit." By using a side tube containing charcoal immersed in liquid air this effect was eliminated.

"If all the cadmium is distilled to the lower half of the bulb and this is then heated to 220 deg. in an oil bath while the upper half is at room temperature, a fog-like deposit is formed on the upper part of the bulb in about fifteen seconds. This deposit is very different from that obtained by cooling the bulb in liquid air. Microscopic examination shows that it consists of myriads of small crystals. According to the condensation-evaporation theory, the formation of this fog is readily understood. Each atom of cadmium, striking the glass at room temperature, remains on the surface for a certain length of time before evaporating off. If the pressure is very low, the chance is small that another atom will be deposited, adjacent to the first, before this has had time to evaporate. But at higher pressures this frequently happens. Now if two atoms are placed side by side on a surface of glass, a larger amount of work must be done to evaporate one of these atoms than if the atoms were not in contact. Not only does the attractive force between the cadmium atom and the glass have to be overcome, but also that between the two cadmium atoms. Therefore the rate of evaporation of atoms from pairs will be much less than that of single atoms. Groups of three and four atoms will be still more stable. Groups of two, three, four atoms, etc., will thus serve as nuclei on which crystals can grow. The tendency to form groups of two atoms increases with the square of the pressure, while groups of three form at a rate proportional to the cube of the pressure. Therefore the tendency for a foggy deposit to be formed increases rapidly as the pressure is raised or the temperature of the condensing surface is lowered.

"On the other hand, according to the reflection theory, there seems to be no satisfactory way of explaining why the foggy deposit should form under these conditions.

"Experiments show clearly that when a beam of cadmium vapor at very low pressure strikes a given glass surface at room temperature, no foggy deposit is formed, although when the same quantity of cadmium is made to impinge against the surface in a shorter time (and therefore at higher pressure) a foggy deposit results. This fact constitutes strong proof of the condensation-evaporation theory.

"A deposit of cadmium of extraordinary small thickness will serve as a nucleus for the condensation of more cadmium at room temperature. Let all the cadmium be distilled to the lower half of the bulb. Now heat the lower half to 60 deg. C. Apply a wad of cotton, wet with liquid air, to a portion of the upper half for one minute, and then allow the bulb to warm up to room temperature. Now heat the lower half of the bulb to 170 deg. C. In about thirty seconds a deposit of cadmium appears which rapidly grows to a silver-like mirror. This deposit only occurs where the bulb was previously cooled by liquid air."

Langmuir calculates from the vapor pressure data for cadmium that "a deposit which forms in one minute with the vapor from cadmium at 60 deg. contains only enough cadmium atoms to cover 3/1000 of the surface of the glass. Yet this deposit serves as an effective nucleus for the formation of a visible deposit."

At lower temperatures where the vapor pressure is much smaller the probability that the atoms striking the glass will fall into positions adjacent to atoms already on the surface becomes very much smaller and the latter re-evaporate before this occurs, consequently there is no apparent condensation. Langmuir states the difference between his point of view and that of Wood and the others quite clearly:

"When an atom strikes a surface and rebounds elastically from it, we are justified in speaking of this process as a reflection. Even if the collision is only partially elastic, we may still use this term. The idea that should be expressed in the word 'reflection' is that the atom leaves the surface by a process which is the direct result of the collision of the atom against the surface.

"On the other hand, according to the condensation-evaporation theory, there is no direct connection between the condensation and subsequent evaporation. The chance that a given atom on a surface will evaporate in a given time is not dependent on the length of time that has elapsed since the condensation of that atom. Atoms striking a surface have a certain average 'life' on the surface, depending on the temperature of the surface and the intensity of the forces holding the atom. According to the 'reflection' theory, the life of an atom on the surface is simply the duration of a collision, a time practically independent of temperature and of the magnitude of the surface forces."

"The above experiments prove," as stated by Langmuir, "that the range of atomic forces is very small and that they act only between atoms practically in contact with each other. Thus a surface covered by a single layer of cadmium atoms behaves, as far as condensation and evaporation are concerned, like a surface of massive cadmium."

In this manner it is possible therefore to account very well for the apparent reflection of cadmium and mercury from glass surfaces and it is seen that these observations are not all in contradiction with Langmuir's theory.

Concentration Drop at a Surface

As pointed out by Langmuir[17] "the diffusion of one gas through another is a phenomenon closely related to heat conduction. In the case of the evaporation of a solid surrounded by a gas, where the vapor must diffuse outward through the gas, the partial pressure of the vapor at the surface of the solid will be less than that of the saturated vapor. In other words, there will be a 'concentration drop' at the surface, just as there is a 'temperature drop' in the analogous case of heat conduction, and a 'slip' in gases where viscosity effects are involved. Analogy suggests that this concentration drop will be inversely proportional to the pressure."

Thus, in the case of a tungsten filament evaporating in argon it is to be expected that there will be a difference in the concentration of the tungsten vapor at the surface and that existing at a distance from this surface, corresponding to the mean free path of tungsten atoms in the particular pressure of argon.

This drop in concentration is a maximum in vacuo and decreases as the pressure of argon is increased, thus tending to prevent more and more the escape of tungsten atoms from the filament. Consequently the actual rate of evaporation of tungsten is decreased by the presence of the gas, as atoms of tungsten colliding with gas molecules tend to be thrown back towards the surface of the tungsten.[18]

[17] J. Am. Chem. Soc. *37*, 419 (1915).
[18] I. Langmuir, Am. Inst. Elect. Eng., Oct. 10, 1913; p. 1895. G. M. J. Mackay, Trans. Illum. Eng. Soc. Sept., 1914.
[19] J. Am. Chem. Soc. *37*, 1139 (1915).

When hydrogen molecules strike a heated filament they are partly dissociated into atoms. As a result there is a drop in concentration of both atoms and molecules at the surface of the filament, and Langmuir has shown[17] how the actual magnitude of this drop can be calculated in this particular case.

Significance of ϵ and its Relation to the Accommodation Coefficient

Mention has been made quite frequently of the quantity ϵ introduced by Langmuir in his discussion of chemical reactions at low pressures. By definition, ϵ is the ratio between the number of molecules actually used up in any reaction and the total number of collisions in unit time. Thus, in the case of oxygen reacting with a heated tungsten filament, ϵ is the ratio between the number of molecules of oxygen disappearing per unit time per unit area, and the number of molecules of oxygen striking unit area per unit time. In the case of reaction between two gases, such as tungsten vapor and nitrogen, ϵ is the ratio between the number of atoms of tungsten combining with N_2 molecules to form WN_2 and the number of collisions between W atoms and N_2 molecules in unit time.

In the latter case, Langmuir finds that ϵ is equal to unity, that is, combination occurs at every collision, while in the reaction between oxygen and tungsten ϵ is extremely small at low temperatures and tends towards unity as the temperature is increased to very high values. In order to account for this observation, Langmuir assumes[19] that oxygen atoms striking the filament condense either as O_2 or O-O, forming either WO_2 or WO on the surface, and these two forms are in equilibrium at any temperature. An oxygen molecule striking WO, forms WO_3 which distills off; on the other hand, an oxygen molecule striking WO_2 does not react with it. Thus the low value of ϵ at lower temperatures is referred to the presence of a very stable layer of WO_2 on the surface, and this view is confirmed by the behavior of hydrogen-oxygen mixtures in presence of a heated tungsten filament.

In a similar manner, Langmuir accounts for low values of ϵ in other reactions between gases and a metal surface by the theory that some constituent adsorbed on the surface acts as a catalytic poison for the reaction. The point is that the low values of ϵ are not due to any reflection of gas molecules from the metal surface. There is every evidence, as has been repeatedly stated above, that the accommodation coefficient is in general approximately equal to unity, and therefore low values of ϵ whenever they are observed in heterogeneous chemical reactions must be accounted for by some condition of the surface.

It has already been stated that the accommodation coefficient for hydrogen in viscosity effects is practically unity. However, in the case of heat transfer there is good evidence that the accommodation coefficient is much lower. Langmuir has observed[20] that at temperatures up to about 1500 deg. K., at a tungsten surface, the accommodation coefficient is about 0.19. "In other words, only about 19 per cent of all the hydrogen molecules striking the filament reach *thermal* equilibrium with it before leaving it." This is in good agreement with the value 0.26 obtained by Knudsen with platinum at room temperature. On the other hand, at high temperatures it is observed that 68 per cent of all the hydrogen molecules striking the filament reach *chemical* equilibrium before leaving it. "The explanation of this apparent paradox is that the surface of the tungsten is largely covered by adsorbed hydrogen at lower temperatures, whereas at the higher temperatures it is practically bare. The 19 per cent thus corresponds to the fraction of the molecules which condenses when they strike a surface already covered with hydrogen, while the 68 per cent represents the fraction condensing on a bare surface."

In the case of the homogeneous gas reactions so far investigated by Langmuir, ϵ has been observed to be unity. If any cases should be found in which it is less than this, the most plausible assumption would be that the molecules must collide in some particular manner in order that reaction should occur, and this might easily be expected where the molecules are large and complex. In another connection the writer recently carried out some calculations on the velocities of decomposition and formation of hydrogen iodide.[21] It was found that the observed velocities could be quantitatively accounted for by the theory that *every collision* between hydrogen and iodine molecules is effective in the formation of hydrogen iodide, and similarly *every* collision between hydrogen iodide molecules is effective in producing hydrogen and iodine. In a similar manner the conclusion was drawn that in the case of the dissociation of iodine vapor (I_2) into atoms, every collision between the atoms must lead to the formation of a molecule of I_2. So that there is no evidence that would point to any reflection in collisions between atoms or simply constituted molecules. It is, however, probable that in the dissociation of such a complex molecule as $(CH_3COOH)_2$ not every collision between the dissociation products would result in the formation of a di-acetic acid. Association would then occur only when certain groups in each molecule are adjacent. The possible existence of such a "steric" factor has been pointed out by other investigators, but further investigation is necessary before any definite conclusions regarding this point can be formed.

[20] J. Am. Chem. Soc. 38, 1147 (1916).
[21] S. Dushman, J. Am. Chem. Soc. 43, 397 (1921).

SUMMARY

In this series of articles the writer has discussed a number of topics which he considered would be of interest to those engaged in experimental work with high vacua. It may be well, therefore, in concluding the series to summarize briefly the subject matter of the different parts and point out their relative connection.

The *sine qua non* for intelligent experimentation at low pressures is a knowledge of the fundamental principles of the kinetic theory of gases. A very brief discussion of the essential points has therefore been given in Part I of the series, together with a more detailed consideration of the laws of flow of gases at very low pressures. This may be regarded as the introduction to the subject matter of the series.

Parts II and III deal with the mechanical and mercury vapor pumps respectively. This section is prefaced by a general discussion of speed of exhaust, and also contains an appendix describing the arrangement of a typical system for high vacuum experiments.

The problem of manometers for low pressures is discussed in Parts IV and V, together with all the essential theoretical principles of the different devices that have been used.

Different physical-chemical methods for cleaning up residual gases in sealed-off tubes are discussed from a theoretical and experimental point of view in Parts VI, VII, VIII, and IX. This includes the adsorption of gases by charcoal and palladium black in Part VI; the adsorption of gases by metals and glass in Part VII; the clean-up of gases by chemical reactions in Part VIII, and the phenomena of electrical clean-up in Parts VIII and IX. In this latter section there is also a discussion of the commercial methods for clean-up of residual gases in incandescent lamps.

The last two installments of the series have been devoted to a consideration of Langmuir's theory of unimolecular layer and its applications. The main reason for discussing this theory, as stated in Part X, is that it presents us with "a point of view of low-pressure phenomena which is of extreme importance for a thorough understanding of the significance of observations in this field." From this point of view we find a correlation between such phenomena as slip, temperature drop, and the rate of attack of a tungsten filament by oxygen at low pressures.

Appendix II contains a summary of formulas from the kinetic theory of gases, molecular data and various constants which have been found useful by the writer and others in high vacuum experimental investigations. The formulas given in Table I have all been discussed in different sections of the present series and are gathered together here for convenience of reference. Table II contains formulas and data which are of importance in dealing with electron emission phenomena in high vacua.[22] Tables III and IV represent an amplification and revision of similar data published by the writer in 1915, as an appendix to a series of papers dealing with the kinetic theory of gases.[23] The reader is therefore referred to this publication for a discussion of the method of deriving these constants and for references to previous literature.

Table III gives molecular data which are of special interest in high vacuum work. The values have been calculated from the equations given in Table I for a temperature of 25 deg. C., as this is the most usual room temperature. In the calculation of the mean free path, the values of η used were those derived from the coefficients of viscosity at 0 deg. C. as tabulated in the publication referred to, corrected for 25 deg. C. by means of Sutherland's formula. The values given for the molecular diameters were taken from the tables given there. For the case of monatomic vapors from metals an approximate value of the molecular (or atomic) diameter (d_m) may be obtained from the density, ρ, and the atomic weight, A, by means of the relation

$$\frac{1}{d_m} = \sqrt[3]{\frac{\rho \times N}{A}} = \sqrt[3]{\frac{\rho \times 6.062 \times 10^{23}}{A}}$$

Hence the number of atoms per cm.^{2} required to form a layer 1 atom deep is

$$1/d^2_m = 10^{15} \times 7.163 \left(\frac{\rho}{A}\right)^{2/3}$$

Comparing the values given in Table IV with those published in 1915, it will be observed that the value of Planck's constant, h, generally accepted at present is 6.55×10^{-27}. This is probably accurate to about 0.15 per cent. The enormous number of investigations carried out in the past few years on the determination of this constant have been summarized by R. T. Birge[24] and R. Ladenburg.[25]

The former arrives at the value $h = 6.5543 \pm 0.0025$, while Ladenburg concludes that the most probable value is 6.54×10^{-27} erg-sec. The value given in Table III is the approximate average of these. This value has been used in calculating the radiation constants in the Planck and Wien equations given in the table. It ought to be noted that in recent publications from the Nela Research Laboratories the value $c_2 = 1.435$ cm. deg. has been used.[26] This agrees with the value $h = 6.564$. On the other hand, the value $h = 6.55$ leads to the derived value $c_2 = 1.432$. For this reason both values of c_2 have been given in the table, and for the present it is recommended that in all investigations dealing with optical pyrometry the value $c_2 = 1.435$ be used.

The value $e/m = 1.769 \times 10^7$ is that given by Ladenburg. Sommerfeld in his book on "Atombau und Spektrallinien" (Nov., 1919), calculates the value 1.7686. In a recent paper[27] Langmuir has drawn attention to a method of deriving h which is independent of Millikan's determination of ϵ (the value given in the table).

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[22] I. Langmuir, Phys. Rev. *2*, 450 (1913), Trans. Am. Electrochem. Soc. *29*, 125 (1916).
A. W. Hull, Phys. Rev. *18*, 31 (1921).
H. D. Arnold, Phys. Rev. *16*, 70 (1920).
[23] GENERAL ELECTRIC REVIEW, *18*, 952, 1042, 1159 (1915).
[24] Phys. Rev. *14*, 361 (1919).
[25] Jahrbuch d. Elektronik, *17*, 93 (1920).
[26] See especially the "1919 Report of Standards Committee on Pyrometry" by W. E. Forsythe, J. Opt. Soc. Am. *4*, 305 (1920).
[27] J. Franklin Inst. May, 1920, p. 605.

APPENDIX II

TABLE I

FORMULAS FROM KINETIC THEORY OF GASES

(1) *Velocity of molecules*

Root-mean-square velocity, $G = \sqrt{\frac{3RT}{M}} = 15,800\sqrt{\frac{T}{M}}$ cm. sec.$^{-1}$

Average (arithmetical) velocity, $\Omega = \sqrt{\frac{8RT}{\pi M}} = 14,551\sqrt{\frac{T}{M}}$ cm. sec.$^{-1}$

Most probable velocity, $W = \sqrt{\frac{2RT}{M}} = 12,900\sqrt{\frac{T}{M}}$ cm. sec.$^{-1}$

(2) *Amount of gas striking unit area per unit time*

$m = (1/4)\ \rho\Omega$, where ρ = density

$= 43.74 \times 10^{-6}\ p\sqrt{\frac{M}{T}}$ gm. cm.$^{-2}$ sec.$^{-1}$ (p in bars).

$= 58.32 \times 10^{-3}\ p\sqrt{\frac{M}{T}}$ gm. cm.$^{-2}$ sec.$^{-1}$ (p in mm. mercury)

n = No. of molecules $= 6.062 \times 10^{23}\frac{m}{M} = 2.653 \times 10^{19}\frac{p}{\sqrt{MT}}$ cm.$^{-2}$ sec.$^{-1}$ (p in bars)

$= 3.535 \times 10^{22}\frac{p}{\sqrt{MT}}$ cm.$^{-2}$ sec.$^{-1}$ (p in mm. mercury)

(3) *Mean free path*

$L = \frac{3\eta}{\rho\Omega} = 17.15 \times 10^{3}\frac{\eta}{p}\sqrt{\frac{T}{M}}$ (p in bars; η = viscosity in c.g.s. units)

$= 12.86\frac{\eta}{p}\sqrt{\frac{T}{M}}$ (p in mm., η in c.g.s. units)

(4) *Speed of exhaust*

$S = 2.303\frac{V}{t}\log\frac{p_1}{p_2}$ (ordinary logs)

where V = volume exhausted (in cm^3).
p_1 = initial pressure.
p_2 = pressure at end of period t (in sec.).

(5) *Rate of flow of gases through an opening or tube*

$F = \frac{Q}{P_2 - P_1} = \frac{9.118 \times 10^3}{W}\sqrt{\frac{T}{M}}$ (cm.^{3} at 1 bar)

where $P_2 - P_1$ = pressure difference in bars.

and $W = \frac{3.184}{D^2}$ for circular opening of diameter D cm.

$= \frac{2.394\ L}{D^3} + \frac{3.184}{D^2}$ for tube of length L, and diam. D.

RATE OF FLOW OF AIR AND HYDROGEN AT LOW PRESSURES AND 20 DEG. C.

L	D	W	F (Air)	F (Hydrogen)
1 cm.	1 cm.	5.58	5,204	19,710
10	1	27.12	1,070	4,053
1	0.1	2712.4	10.70	40.53
10	0.1	24,258	1.196	3.60

[NOTE.—These relations are valid for pressures so low that the mean free path is equal to or greater than D.]

For pump exhausting through resistance

$$\frac{1}{S} = \frac{1}{S_p} + \frac{1}{F}$$

where S = observed speed of exhaust.
S_p = speed of pump through negligible resistance.

TABLE II

LAWS OF ELECTRON CURRENTS IN HIGH VACUA

(1) *Richardson's Equation*: $i = A\sqrt{T}\,e^{-b/T}$

If i = saturation current in amperes per cm.² at temperature T, the values of A and b are as follows:

Substance	A	b	i at 2000 K
W	23.6×10^{6}	52,500	0.0042
Mo	21.0×10^{6}	50,000	0.015
C (untreated)		48,000	
Th	200×10^{6}	39,000	30.0
Oxide coated Pt.	16×10^{4}	20,000	325

(2) *Space Charge Equations* (*Langmuir*)

(1) For filament in axis of cylinder of radius r cm. Current per cm. length, $i = \frac{2\sqrt{2}}{9}\sqrt{\frac{e}{m}}\cdot\frac{V^{3/2}}{r} = \frac{14.69\times10^{-6}}{r}V^{3/2}$ amps., where V = anode volts.

(2) For parallel plane electrodes separated by d cm. Current per cm.², $i = \frac{2.33\times10^{-6}}{d^2}V^{3/2}$ amps

(3) *Effect of Magnetic Field* (*Hull*)

For filamentary hot cathode in axis of cylindrical anode of radius r

$$H = \sqrt{\frac{8m}{e}}\cdot\frac{V^{1/2}}{r}$$

where H = magnetic field strength required to decrease electron current to zero with anode potential V. For H in gauss, V in volts, and r in cm.

$$H = \frac{6.725\sqrt{V}}{r}$$

TABLE III

MOLECULAR DATA

	H_2	He	N_2	O_2	A	Hg	CO	CO_2	H_2O
Mass of molecule Unit = gm. $\times10^{-24}$	3.326	6.582	46.23	52.78	65.79	330.9	46.20	72.59	29.73
Mean velocity at 25 deg. C. Unit = cm. $\times10^{5}$ sec.$^{-1}$	1.922	1.366	0.515	0.482	0.432	0.193	0.515	0.411	0.643
Average velocity at 25 deg. C. Unit = cm. $\times10^{5}$ sec.$^{-1}$	1.769	1.257	0.475	0.444	0.398	0.177	0.474	0.379	0.592
Mean free path (in cm.) at 25 deg. C. and 1 bar	19.2	29.6	10.0	10.7	10.6	[3.24]*	9.92	6.68	[6.03]*
Molecular diameter (d) Unit = cm. $\times10^{-8}$	2.4	1.91	3.15	3.0	2.9	3.0	3.2	3.3	2.9
$(1/d)^2\times10^{-15}$ Number of molecules per cm.²	1.74	2.74	1.01	1.11	1.19	1.11	0.98	0.92	1.19
Mass of gas striking 1 cm.² per sec. at 25 deg. C. and 1 bar Unit = gm. $\times10^{-6}$	3.597	5.062	13.42	14.33	16.01	35.89	13.42	16.81	10.76
Number of molecules striking 1 cm.² per sec. at 25 deg. C. and 1 bar Unit = 10^{17}	10.82	7.693	2.837	2.717	2.433	0.1085	2.837	2.317	3.620

* Values in square brackets refer to 0 deg. C.

NOTE: 1 bar = 0.75×10^{-3} mm. mercury.

TABLE IV
ATOMIC AND ELECTRONIC CONSTANTS

Volume per gram-molecular weight of ideal gas.	
At 0 deg. C. and 1.01323×10^6 bars (760 mms. *Hg*)	$V=22{,}412$ cm.^{3}
At 0 deg. C. and 1×10^6 bars (750 mms. *Hg*)	$V=22{,}708$ cm.^{3}
Gas constant	$PV/T=R=83.15\times10^6$ erg/deg. $=1.987$ cal/deg.
Faraday Constant	$F=96{,}500$ coulombs.
Unit electric charge	$\epsilon=4.774\times10^{-10}$ e.s.u. $=1.591\times10^{-20}$ e.m.u.
Number of molecules per gram molecular weight	$F/\epsilon=N=6.062\times10^{23}$
Number of molecules per cm^3	
At 0 deg. C. and 1.01323×10^6 bars	$N/V=2.7048\times10^{19}$
At 0 deg. C. and 1×10^6 bars	$=2.6696\times10^{19}$
Boltzmann gas-constant	$R/N=k=1.372\times10^{-16}$ erg./deg.
Kinetic energy of a molecule at 0 deg. C.	$=\frac{3}{2}k\times273.1=5.621\times10^{-14}$ erg.
Mass of hydrogen atom	$m_H=1.008/N=1.663\times10^{-24}$ gm.
Ratio of charge to mass of electron	$\epsilon/m_0=1.769\times10^7$ e.m.u. gm.$^{-1}$
Mass of electron	$m_0=8.995\times10^{-28}$ gm.
Velocity of light	$c=2.9986\times10^{10}$ cm. sec.$^{-1}$
Constant of quantum theory	$h=6.55\times10^{-27}$ erg. sec.
Constant of Einstein's photo-electric equation	$\frac{h}{\epsilon}=1.372\times10^{-17}$ (c.g.s. units)
Potential corresponding to frequency ν	$V=h\nu/\epsilon=4.115\times10^{-15}\,\nu$ (volts)
Potential corresponding to wave length λ (Angstroms)	$V=\frac{hc}{\lambda\epsilon}=12{,}340/\lambda$ (volts)
Constant in specific heat equations	$\beta=h/k=4.774\times10^{-11}$ sec. deg.
Planck's Distribution Law for "Black Body"	$I_\lambda=\dfrac{c_1\lambda^{-5}}{e^{\frac{c_2}{\lambda T}}-1}$

Radiation Constants

$c_1=2\pi c^2h=3.700$ erg. cm.$^{-2}$ sec.$^{-1}$

$c_2=ch/k=1.432$ (*1.4350*) cm. deg.

$$\lambda_m T=\frac{ch}{4.9651}=0.2883 \text{ cm. deg. (Wien's displacement constant)}$$

$$I_m=\frac{2\pi k^5(4.9651)^5\,T^5}{c^3h^4(e^{4.9651}-1)}=1.305 \text{ erg. cm.}^{-3}\text{ sec.}^{-1}\text{ deg.}^{-5}\text{ (maximum intensity)}$$

Stefan-Boltzmann law: Total energy radiated from surface $=\int_0^\infty I_\lambda\,d\lambda=\sigma(T^4-T_0^4)$

$$\sigma=\frac{12\pi\times1.0823\,k^4}{c^2h^3}=5.722 \text{ erg. cm.}^{-2}\text{ sec.}^{-1}\text{ deg.}^{-4}$$

Rydberg's constant (Bohr's theory).

$$\nu_0=2\pi^2m_0\epsilon^4h^{-3}=3.287\times10^{15}\text{ sec.}^{-1}$$

Radius of first Bohr ring of hydrogen atom.

$$r_1=\frac{\epsilon}{m_0}\cdot\frac{h^2}{4\pi^2\epsilon^3}=0.5294\times10^{-8}\text{ cm.}$$

Chemical constant, $C=C_0+1.5\log M$

where M = molecular weight

$$C_0=\log\frac{(2\pi)^{3/2}k^{5/2}}{N^{3/2}h^3\times1.013\times10^6}$$

$= -1.5877$ (press. in atmospheres).

$= \ \ 1.2931$ (press. in mm. of mercury).

The Randfontein Central Pumping Plant

By W. D. Galpin

Engineer, South African General Electric Co., Ltd.

This article describes an underground pumping plant having a capacity of [illegible] against a head of 2600 feet, which makes it the largest or one of the largest plants [illegible]. The installation was made to replace and centralize in one location the [illegible] 170 individual pumping units scattered in small groups along the length of the five shafts of the Company and thus secure the highest possible efficiency and reliability of operation. How well the equipment accomplishes its economic purpose is indicated by the author's statement that the saving effected by the plant in one year repays the investment although this amounts to about a half million dollars. A brief description is given of the motors and pumps of the new units, the control switchboard, and the treatment of the water to neutralize its acidity and reduce the amount of dirt carried in suspension.—Editor

The gold mines of the Randfontein Central Gold Mining Co., Ltd., are situated about 28 miles west of Johannesburg, South Africa. A considerable amount of water accumulates at the bottom of these mines, on account of their depth, and continuous pumping is necessary in order to render the ore workable for 3000 or more feet below the surface. In the past, five of the shafts of this Company each had its own pumping equipment; and as none of the pumps used was suitable for a lift of more than 800 feet, a series of three or four pumping stations were required per shaft, each of these often containing as many as five or six pumps, making a total of about 170 altogether.

Recently it was decided to eliminate these many stations and to centralize all the pumping at one point where a large and efficient plant could serve the five separate shafts.

The mine water has an acidity varying from 0.01 to 0.06 per cent (in terms of sulphuric acid), due mainly to the oxidation of the pyrites in the gold bearing reef and surrounding rock, and is also very dirty, containing a considerable amount of mud and grit, different analyses indicating as much as 0.12 to 0.137 per cent of solids by weight, the latter figure representing about 1 lb. per 30 gal.

Water of this nature can be handled by medium-lift reciprocating pumps although the resulting wear on plungers, valves, etc., is rather severe. With large high-lift centrifugal pumps, however, neutralization of the acidity and removal of as much of the sediment as

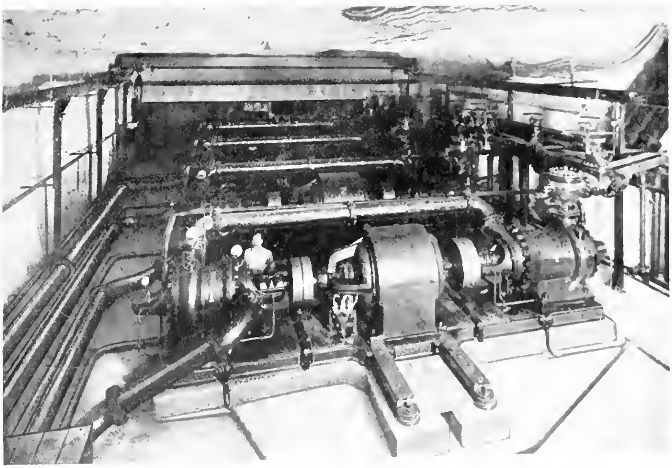

Fig. 1. The New Centralized Pumping Station of the Randfontein Central Gold Mining Co., Ltd., is Located in an Underground Chamber Cut in Solid Rock and Consists of Four Pumping Units Each Comprised of a Motor and Two Direct-connected Pumps in Series

possible is considered absolutely essential. This procedure not only reduces the cost of replacements to a minimum, but also prevents the formation of scale in the pipes which is very difficult and expensive to remove, especially from a vertical delivery column two or three thousand feet long.

The new central pumping station, as will be seen from Fig. 1, is a large chamber cut out of the solid rock and containing four units each consisting of:

One 4-pole, 1750-h.p. (30 deg. C.), 1500/1475-r.p.m., 3-phase, 50-cycle, 2000 volts delta, phase-wound induction motor, with shaft extended at each end, and direct connected by rubber bushed pin type flexible couplings to No. IV B.e.d. 5+8 stage high-lift centrifugal pump capable of delivering 83,000 gal. per hour against 2600 ft. head with suction half of 5 stages at one end of the motor and pressure half of 8 stages at the other.

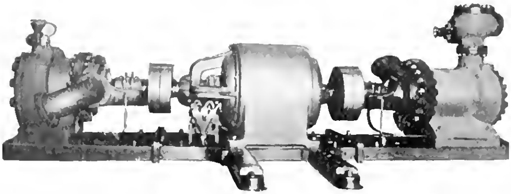

Fig. 2. One of the Pumping Sets, Showing the Motor, Couplings, and Two Halves of the Pumping Unit

Arrangements have now been made so that all the water is conveyed to the north vertical shaft by means of flumes, pipes, tunnels, etc. Here lime is added to reduce the acidity and prevent corrosion of the pumps, neutralization to the methyl-orange stage being considered satisfactory for practical purposes. The water then passes through an ingenious arrangement of settling sumps, the result of a very thorough and systematic investigation, including numerous experiments with tanks of various sizes, etc., which removes almost all the suspended matter. The main channel can be diverted into any one or more of six large sumps where, after passing through sieves to eliminate foreign substances, such as wood, pieces of candle, etc., the velocity of the water is greatly reduced and the impurities soon deposited in the form of a thick sludge. Across the end of each sump opposite to that at which the water enters are two sets of narrow parallel lip launders covering about one-quarter of the surface. These skim off the clean water and deliver it into a central flume which discharges into the main storage dam. The clean water thus obtained contains only 0.007 per cent of solids by weight. At intervals of about a week to ten days the incoming stream is cut off from each sump one at a time, and after the clear surface water has been drawn down the accumulated sludge is removed and the sump placed in service again. This sludge does not contain enough gold to render its extraction payable, due to the difficulties of satisfactory treatment and the large amount of expensive chemicals required.

The whole unit, consisting of motor and two halves of pump as shown in Fig. 2, is mounted on a common base plate provided with slide rails to facilitate removing the motor for internal inspection or repairs, and weighs 48,000 lb., the overall dimensions being: length 25½ ft., width, 5½ ft., and height, 6 ft.

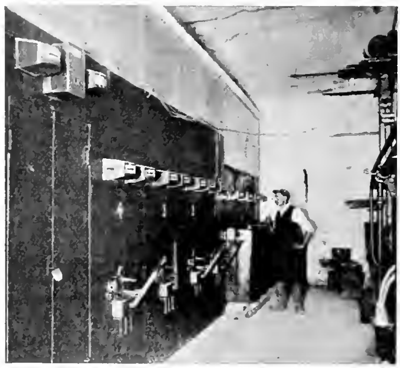

Fig. 3. Switchboard for Controlling the Operation of the Pumping Plant Illustrated in Fig. 1

The switchboard controlling these four pumps, illustrated in Fig. 3, is comparatively simple and consists of a sheet-steel housing at the termination of the incoming power lines, with panels on which are mounted:

One power totalizing meter equipment.
Four T. P. S. T. primary oil circuit breakers with overload protection.
Four motor secondary control equipments consisting of drum controllers, with starting resistors and short circuiting contactors.

Interlocks are provided so as to prevent the closing of any oil circuit breaker unless the corresponding controller is in the "off" position thus avoiding the possibility of any injury to the equipment due to a motor being thrown on the line without starting resistance in circuit.

All the electrical equipment was manufactured by the General Electric Co., and the pumps by Messrs. Sulzer Freres, Winterthur, Switzerland. Figs. 4 and 5 show the excellent characteristics of the motors and pumps comprising these units, the efficiencies particularly being very much superior to those obtained with the smaller outfits previously used.

Four 10-inch steel suction pipes convey the clean water from the main storage dam to each pump, where after passing through the five stages of the suction half it is transferred to

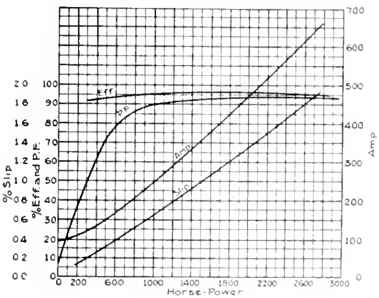

Fig. 4. Motor Characteristic Curves of One of the Pumping Units

the other end of the motor and passes through the eight stages of the pressure half to the delivery end of the unit. The four pumps are arranged so that each of them can be connected to any of the three 10-inch pipes leading to the surface. These delivery columns are provided with expansion joints in the middle, are 2500 feet long, and weigh 90 tons each.

The total output of the four pumps in this station is 332,000 gal. per hour or nearly

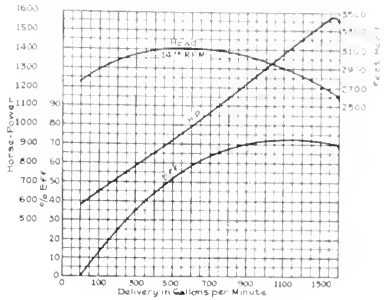

Fig. 5. Pump Characteristic Curves of One of the Pumping Units

8,000,000 gal. per day against a head of 2600 ft., making this one of the largest if not the largest underground pumping plant in the world.

At present only two pumps are used at a time but three will be required when more of the old equipment has been removed, leaving one as a spare. Space has also been provided in the pump chamber for the addition of a fifth unit at some future time. The north vertical shaft where these pumps are installed is at present being sunk to a depth of 4000 ft. and this will subsequently be increased to 5000 ft., when it is expected to add a practically duplicate equiqment at the bottom of the mine to feed the present plant.

The new centralized pumping station has already eliminated the necessity for operating 70 of the old pumps, and is shortly expected to permit the removal of an additional 50. In thus superseding 120 smaller pumps, the greatly reduced operating and maintenance costs, together with the increased overall efficiency obtained, will enable the present plant to pay for itself in one year, in spite of the fact that it represents an investment of about one-half million dollars.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Balancing

Balancing High-Speed Rotors. Schein, A.
Am. Mach., July 28, 1921; v. 55, pp. 121-125.
(Fundamental principles, with examples.)

Brakes, Dynamic

Dynamic vs. Mechanical Braking. Richardson, George W.
Assoc. Ir. & St. Elec. Engrs., Aug., 1921; v. 3, pp. 265-275.
(Description of equipment and experiences at the American Bridge Company's plant at Pencoyd, Pa.)

Capacitance

Comparison of Small Capacities by a Beat Note Method. Thomas, P.
Elec. Jour., Aug., 1921; v. 18, pp. 349-350.

Cascade Control

Some Developments in Multi-Speed Cascade Induction Motors. Creedy, F.
I. E. E. Jour., May, 1921; v. 59, pp. 511-537.
(Reviews previous work, gives theory of the cascade motor from a new point of view and describes some new windings.)

Demand Factor

Reducing Manufacturing Costs by Studying Power Demand. Lowry, R. S.
Elec. Wld., Aug. 6, 1921; v. 78, pp. 257-258.
(Author believes a careful study will disclose wastes.)

Electric Current Rectifiers

Glass Rectifiers of the Higher Capacities. (In German.)
Zeit. des Ver. Deut. Ing., July 23, 1921; v. 65, p. 807.
Short description, with wiring diagram, of a Siemens-Schuckert 120-ampere rectifier consisting of two 60-ampere tubes in parallel.)

Electric Distribution

Three-Phase Supply to Scott-Connected Transformer Banks Under Various Conditions of Two-Phase Loading. Stubbings, G. W.
Elec. Rev. (Lond.), July 15, 1921; v. 89, pp. 76-78.
(Mathematical discussion with diagrams.)

Electric Drive—Coke Plants

Alternating Current in By-Product Plants. Dunn, W. Y.
Assoc. Ir. & St. Elec. Engrs., Aug., 1921; v. 3, pp. 249-256.
(Discusses the advantages and disadvantages of A.C. for this purpose, and describes equipment of the Tenn. Coal, Iron and R.R. Company, Fairfield, Ala.)

Direct Current in By-Product Plants. Winters, E. P.
Assoc. Ir. & St. Elec. Engrs., Aug., 1921; v. 3, pp. 257-263.
(Discusses the application of D.C. to by-product plants.)

Electric Furnaces

Electric Furnaces, Laboratory Types. Griffiths, Ezer.
Beama, July, 1921; v. 9, pp. 12-18.
(Serial article on the construction and operation of laboratory furnaces.)

Electric Locomotives

Mechanical Advantages of Electric Locomotives Compared with Steam Engines. Raven, V. L. R.
Elec. Rev. (Lond.), Aug. 5, 1921; v. 89, pp. 194-195.
(Abstract of paper before the British Engineering Conference, 1921.)

Operating Characteristics of the Electric Locomotive. Storer, N. W.
Rwy. Rev., Aug. 6, 1921; v. 69, pp. 169-173.
(Advantages offered the operating man, and the uses of the various types of motors.)

Electric Motors—Starting Devices

New Method of Starting Direct Current Railway Motors: the Induction Starter. Givelet, Armand. (In French.)
Revue Gén. de l'Elec., July 23, 1921; v. 10, pp. 133-137.
(New device would do away with the starting resistances.)

Electric Transmission Lines

Nomograms and New Auxiliary Charts for Electrical Calculation of High-Tension Transmission Lines. Lavanchy, Ch. (In French.)
Revue Gén. de l'Elec., July 9, 1921; v. 10, pp. 47-53.
(Explains the construction and use of multiple nomograms in transmission line calculation.)

Transmission Line and Transformers. Evans, R. D. and Sels, H. K.
Elec. Jour., Aug., 1921; v. 18, pp. 356-359.
(Theory of the effect of transformers on transmission lines.)

Voltage Regulation and Insulation for Large Power, Long Distance Transmission Lines. Baum, Frank J.
A.I.E.E. Jour., Aug., 1921; v. 40, pp. 643-665.
(Lengthy paper on theory and testing of lines and insulators.)

Electrical Machinery

Dimensions and Output. Widmark, Lawrence E.
A.I.E.E. Jour., Aug., 1921; v. 40, pp. 665-667.
Author suggests a new fundamental formula for use in designing rotor dimensions.)

Electrical Machinery—Fires

Combating Fires in Transformers and Oil Switches. Sinclair, C. T.
Elec. Wld., Aug. 20, 1921; v. 78, pp. 357-359.

Dirt Plus Static as Cause of Turbo-Generator Fires. Higgins, D. D.
Power, Aug. 9, 1921; v. 54, pp. 206-207.
(Describes tests and suggests methods of prevention.)

Electrical Machinery Temperature

Determination of Maximum Temperature of Heavily Insulated Coils. Jakob, Max. (In German.)

Arch. fur Elek., June 10, 1921; v. 10, pp. 47-56.

(Reports on tests conducted by Lubowski of the A.E.G. Research Laboratory. Presents a direct method of measuring the heat conductivity of coil insulation.)

Gearing

Progress and Problems in Mechanical Power Transmission. Kutzbach, K. (In German.)

Zeit. des Ver. Deut. Ing., June 25, 1921; v. 65, pp. 673-678.

(Illustrated account of high-speed gears for turbine-driven ships, stationary turbine installations, locomotives, etc. Also modern belt and rope drive. Serial.)

Headlights, Electric

Motor Car Headlights: Ideal Requirements and Practical Solutions. Garrard, Maj. A.

Illum. Engr., Apr., 1921; v. 14, pp. 92-107.

(General introduction to a discussion held at a meeting of the Illuminating Engineering Society of London.)

Hydroelectric Plants

Semi-Automatic Operation Economical in Small Hydro Stations. Stauffacher, E. R. and Clingwald, G.

Elec. Wld., July 30, 1921; v. 78, pp. 213-216.

(Conversion to the semi-automatic system has saved the Southern California Edison Company about 45 per cent in a particular station.)

Magnetos

Magnetos for Ignition Purposes in Internal Combustion Engines. Watson, E. A.

I.E.E. Jour., May, 1921; v. 59, pp. 445-490.

(With a bibliography and extensive discussion.)

Monel Metal

Monel Metal Has Definite Magnetic Properties. Burrows, Charles W.

Elec. Wld., July 16, 1921; v. 78, pp. 115-116.

(Shows test results.)

Pipes and Piping

Standard Methods of Identification of Fluids Conveyed by Pipes in Power Houses and Industrial Plants.

Mech. Engng., July, 1921; v. 43, pp. 498-499.

(Gives color schemes used by several concerns for indicating various fluids.)

Power Factor

Electrical Characteristics of Transmission Circuits—XV. Synchronous Motors and Condensers for Power-Factor Improvement. Nesbit, Wm.

Elec. Jour., Aug., 1921; v. 18, pp. 365-373.

Power Factor Correction and Its Relation to Plant Operation. Vanderwaart, P. T.

Assoc. Ir. & St. Elec. Engrs., July, 1921; v. 3, pp. 213-239.

(Causes of low power factor and its remedies.)

Protective Apparatus

Protection Against Earths. Roth, A.

Elec'n (Lond.), July 22, 1921; v. 87, pp. 101-103.

(Abstract translation from BBC Mitteilungen.)

Pumps, Centrifugal

Comparison between [illegible] and Turbo [illegible] Leupton, H. [illegible]

Engin. (Lond.), July 8, 1921; v. 112, pp. 74-76.

[illegible]

Railroads Electrification

Some Operating Results [illegible] N. & W. [illegible]

Ry. Elec. Engr., July, 1921; v. [illegible], pp. 271-272.

(Operating costs for the N. & W. electrification. Makes comparison with steam operation.)

Resistors

Electrical Resistance Material. Kerr(?), [illegible], Walter.

Assoc. Ir. & St. Elec. Engrs., Aug., 1921; v. 3, pp. 241-247.

(Short article on the types used in the steel plant.)

Steam Plants

High Pressure Steam Up to 60 Atmospheres in Power and Heating Plants. Hartmann, O. H. (In German.)

Zeit. des Ver. Deut. Ing., June 25, 1921; v. 65, pp. 663-671.

(Shows that steam at 60 atmospheres is practical and results in considerable economy. Serial.)

Steam Turbines Lubrication

Recooling the Lubricating Oil from Turbine Bearings and Reduction Gears. Derby, S. E.

Power, Aug. 2, 1921; v. 54, pp. 179-181.

(On methods of operation and theory of lubricating systems.)

Steel Electrometallurgy

Compares Costs of Melting Steel.

Iron Tr. Rev., July 21, 1921; v. 69, pp. 167-170.

(Comparative manufacturing cost statistics for electric and open-hearth steel.)

NEW BOOKS

Die Symbolische Methode zur Losung von Wechselstromaufgaben. Ring, Hugo. 51 pp., 1921, Berlin, Julius Springer.

Electrical Machinery. Annett, T. A. 431 pp., 1921, N. Y., McGraw-Hill Book Company, Inc.

Engineering Instruments and Meters. Griffiths, Edgar A. 360 pp., 1921, N. Y., D. Van Nostrand Company.

Engineering of Power Plants. Ed. 2. Fernald, Robert H. and Orrok, George A. 595 pp., 1921, N. Y., McGraw-Hill Book Company, Inc.

Industrial Organization and Management. Diemer, Hugo. 291 pp., 1921, Chicago, LaSalle Extension University.

Report of Overhead Systems Committee, N. E. L. A. 204 pp. N. Y., Published by National Electric Light Association, 29 W. 39th St., N. Y. Price to members, $2.00, other $4.00.

Report of Prime Movers Committee, N. E. L. A. 360 pp. N. Y., Published by National Electric Light Association, 29 W. 39th St., N. Y. Price to members, $3.50, others $7.00.

Third Power Kink Book. 264 pp., 1921, N. Y., McGraw-Hill Book Company, Inc.

Wireless Telegraphy with Special Reference to the Quenched-Spark System. Leggett, Bernard. 485 pp., 1921, N. Y., E. P. Dutton & Company.

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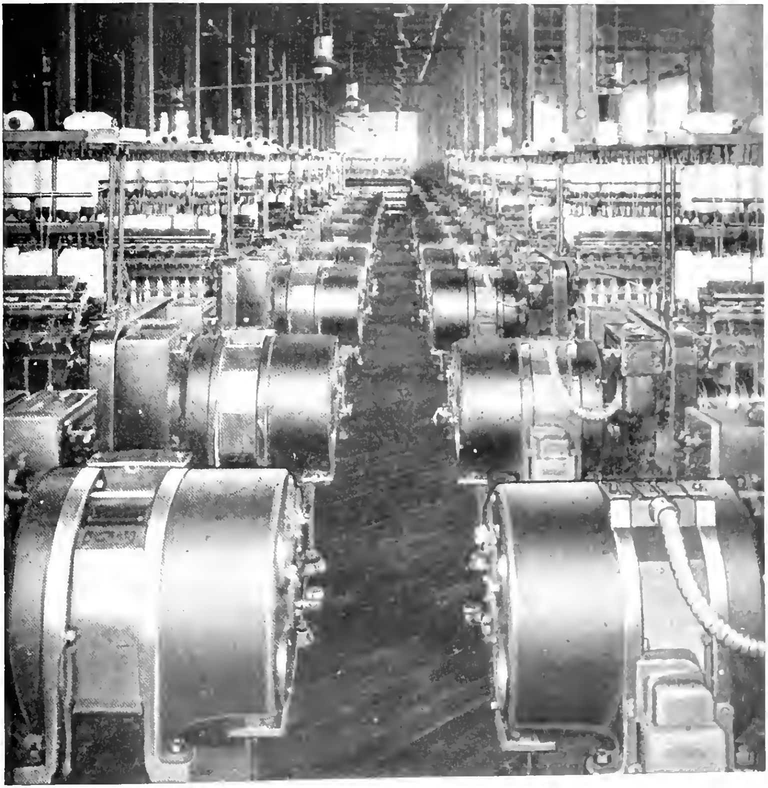

SINGLE-PHASE VARYING-SPEED BRUSH-SHIFTING COMMUTATOR MOTORS DRIVING SPINNING FRAMES

(See article, page 921)

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A Monthly Magazine for Engineers

Manager, M. P. RICE   Editor, JOHN R. HEW[illegible]   [illegible]

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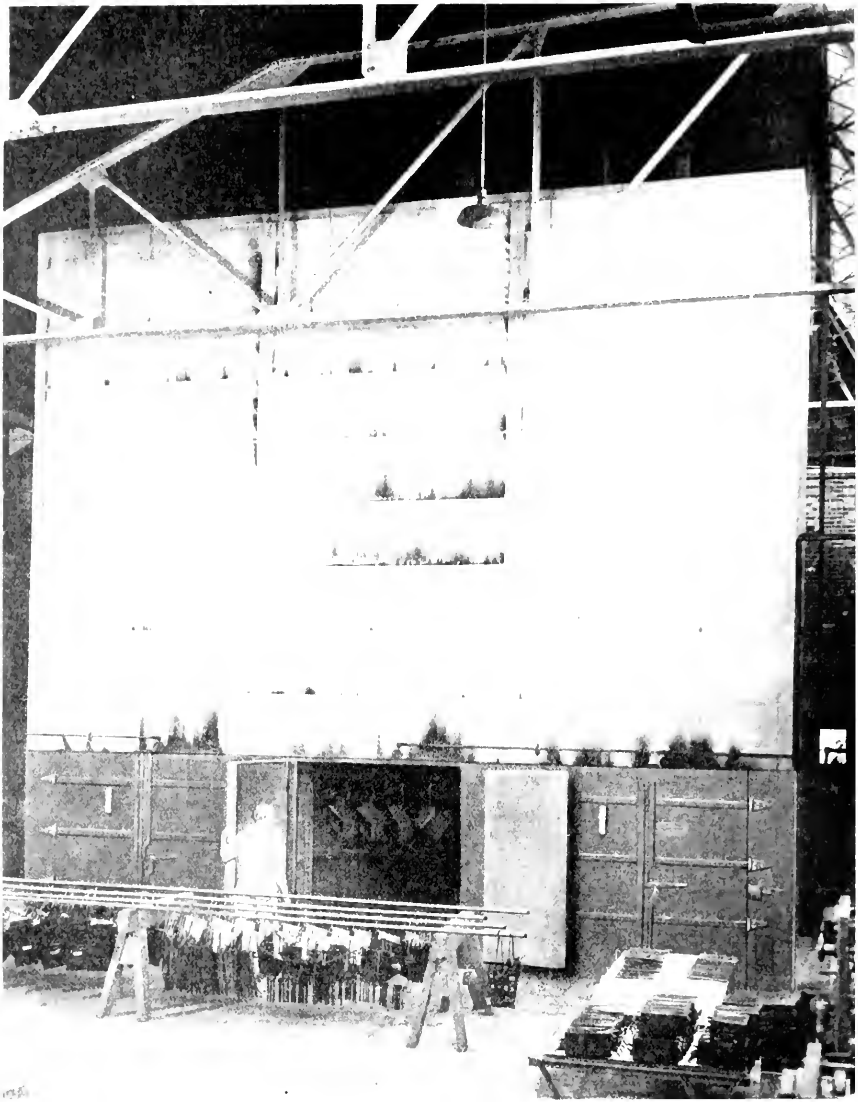


Vertical, Electrically Heated, Intermittent Type, Water-japan Ovens at Sprague Works, General Electric Company. Two of the ovens have a maximum capacity of two tons, the third three tons per charge
(See article, page 935)

GENERAL ELECTRIC REVIEW

ELECTRICAL PRECIPITATION

The conduct of many industrial processes is necessarily accompanied by the formation of mists, fumes, or dust-laden gases. In the manufacture of metallurgical cement, and chemical products, the discharge of valuable by-products to the atmosphere frequently occurs in volumes sufficient to lower the efficiency of manufacture materially. Even though the material content be of no commercial value, as in the case of coal smoke, the liberation of laden gases in quantity may be adjudged a public nuisance.

It is interesting to note that in many cases electricity furnishes the best solution to the problem of cheaply and efficiently recovering finely divided solid or liquid particles from the gas in which they are suspended, and also that the phenomenon of electrical precipitation was first observed long before stern economics and congested population required its application. In fact we have records of experiments which illustrate its fundamental principles and which were performed at least eighty years before Dr. F. G. Cottrell began the work which has resulted in the present broad application of the process to which his name has been applied.

The first successful electrical precipitator of industrial magnitude was constructed in accordance with the designs and patent specifications of Dr. Cottrell, and was placed in operation at the plant of the Selby Smelting and Lead Company, Vallejo Junction, California, in 1907. The rapid development of the process since that time is evidenced by the immense installation located at the Anaconda smelter of the Anaconda Copper Mining Company, having a capacity for treating 750 times the volume of gas handled at the Selby plant.

The operation of the process is based on the fact that charged electrodes exert forces of repulsion and attraction on surrounding electrically charged material particles. The application of the phenomenon to practical use is accomplished by passing the gas which is to be treated between two electrodes which are maintained at a high potential difference by a unidirectional current, one of the electrodes being of such shape as to facilitate electrical discharge and the other to minimize it. The use of fixed instead of alternating polarity maintains constant the direction in which the electrostatic forces are applied to the material particles, with the result that the particles are continuously [illegible] toward one electrode, on which they collect. G[illegible] not be precipitated and collected in this manner, and the process is therefore not capable of separating true gases as such; however there are special cases wherein, by properly adjusting the temperature of the mixture, fractional precipitation may be employed to separate gases which have different condensation temperatures.

In general the field of the Cottrell process is found to be in: (a) the recovery of valuable materials, either solids or liquids, which are carried in suspension in gases; (b) the cleaning of gases for discharge into the atmosphere; and (c) the cleaning of gases for use. In many cases the process serves more than one of these purposes simultaneously. For example, a large cement plant was forced to install a precipitator to clean its stack gases, in order to prevent the dust settling on the surrounding agricultural district; it was soon found that the precipitated dust contained valuable amounts of potash, and the recovery of this material provided a very good return on the capital investment. Among the varied applications of the Cottrell process may be mentioned: the recovery of valuable metals from smelter smoke; the cleaning of gases from cement kilns; the cleaning of sulphur dioxide gas for use in sulphuric acid manufacture; the cleaning of blast furnace gases; the precipitation of coal smoke; the precipitation of acid mists; the detarring of illuminating gases; the collecting of phosphoric acid; and the cleaning of air.

As illustrating the important part played by electrical precipitation in industrial processes the following data, given by P. E. Landolt, in *Chemical and Metallurgical Engineering*, Vol. 25, No. 9, are of interest. He states that the total investment in Cottrell installations in copper smelters is $5,000,000, over 8,000,000 cubic feet of gas being treated per minute, with a recovery of at least 5,000,000 pounds of copper per annum, yielding a net return of 20 per cent on the investment. In lead smelters, precipitators total $3,000,000 in value, and recover 15,000,000 to 20,000,000 pounds of lead per annum. In tin smelting plants the investment in precipitation is nearly $400,000 with a saving of at least 2,000,000 pounds of tin yearly. In silver refineries, while the investment in precipitators [illegible] $300,000, the total recovery of silver alone [illegible] 500,000 ounces per annum, in addition to which considerable gold is saved.

A complete description of the theory and equipment of the Cottrell process of electrical precipitation appears on page 910 of this issue of the REVIEW. Subsequent issues will contain articles treating [illegible]

The Cottrell Process of Electrical Precipitation

By H. A. Winne

Power and Mining Engineering Department, General Electric Company

The Cottrell process whereby fume and dust particles can be electrically precipitated from the gases in which they are suspended is coming into extensive use for recovering the material particles, for cleaning the gases, or for both purposes. In the following article the theory of the process is carefully explained, and then a comprehensive description is given of the construction and operation of the types of precipitator that have been found to be most successful. Information is then furnished as to the amount and character of the electrical power required, the necessary electrical equipment, and the field for application of the Cottrell process. Our December issue will contain an article on the Cottrell precipitator at the plant of the Duquesne Reduction Company.—Editor.

History

The fact that fume and dust can be precipitated electrostatically has been known since 1824, and various investigators have experimented with this method of cleaning gases. However, it remained for Dr. Fredrick G. Cottrell, while a professor in the University of California, in 1906, to realize the commercial possibilities of the application of this process and to work out the technical details.

Because of Dr. Cottrell's pioneer work on the subject, the precipitation of fume and dust by electricity is universally known as the Cottrell Process. Dr. Cottrell's first laboratory work on the process was in connection with the precipitation of sulphuric acid mist, and the first commercial installation was for the purpose of recovering the mist escaping from kettles of boiling sulphuric acid, used in parting dore bullion, at the plant of the Selby Smelting and Lead Company, Vallejo Junction, California. This first plant was put in operation in 1907, and it is a high tribute to the ability of Dr. Cottrell and his associates that the original plant is still in successful operation. It is a far cry from the Selby precipitator, with an electrical installation of 5-kv-a. capacity treating possibly 4000 cubic feet of gas per minute, to the immense Anaconda plant, with its sixteen 75-kv-a. electrical sets and its treaters capable of handling 2,000,000 to 3,000,000 cubic feet of gas per minute, but Dr. Cottrell's ideas and inventions* made both possible.

Theory of the Cottrell Process

In brief, the process of electrostatically precipitating fume and dust, or the Cottrell process, consists of simply passing the fume or dust-laden gas between two suitably shaped electrodes which are charged with a high, unidirectional potential difference. One of the electrodes is so shaped as to facilitate electrical discharge, and the other to minimize it. As a result of the discharge between the two electrodes, the gas is ionized and the material particles, or dust, receive charges of the same polarity as the "discharge electrode." They are consequently driven away from the discharge electrode and attracted to the surface of the "collecting electrode," on which they lodge and from which they can be removed at intervals by rapping the electrodes. When dislodged they fall into hoppers beneath the precipitator.

A more detailed description of the theory of the process follows:†

"The precipitation, or removal of suspended particles from gases by electrical means, is accomplished through the use of a strong electric or so-called 'static' field. An electrically charged particle when in an electric field between two electrodes tends to move towards the negative electrode, if the charge is positive, and towards the positive electrode, if negative.

"The suspended particles receive electric charges in two ways: First, if the particles are suspended in gases which are 'ionized,' they receive charges from the gases directly. Second, if the gases pass through an electric field they receive charges by 'induction.'

"A gas may be ionized by intense heat, cathode or Roentgen rays, radium emanations, and by other means. In electrical precipitation advantage is taken of the fact that a strong electric field will cause ionization of a gas, and the familiar corona discharge is evidence that this ionization is taking place. Gas molecules are normally balanced electrically, being made up of a nucleus having a positive charge and a number of electrons having negative charges which total and balance the positive charge of the nucleus. Ionization is the phenomenon of separating

* The Cottrell process is fully covered by patents, and licenses must be obtained for its use. The Research Corporation, New York City, controls the application of the process to all industries but cement mills and in all states of the United States except Arizona, California, Idaho, Nevada, Oregon, and Washington. The Western Precipitation Co., Los Angeles, Cal., and Philadelphia, Pa., has rights to all applications in these six states, and to cement mills throughout the United States. In most foreign countries the patents are controlled by the International Precipitation Co., Los Angeles, Cal., or their agents.

electrons from the positive nuclei. The gas molecules or what remains of them are now charged positively and are called positive 'ions'; the negative electrons may remain free or they may become attached to neutral molecules and so make up negative ions.

"The ions and electrons become attached to the suspended particles and the resulting agglomerates move across the electric field because of the force exerted upon the balanced electric charges they carry.

"Suspended particles in an electric field receive charges by induction similarly to the way in which a glass rod rubbed with silk induces charges upon a pitch ball in the familiar classroom experiment. The particles having the induced charges upon them move towards one or the other of the electrodes, depending upon the sign of the charge and the position of the particles with respect to the electrodes. It is possible, however, that precipitation is more largely due to ionization of the gases than to induction.

"If, in apparatus for the electrical precipitation of suspended particles, one of the electrodes is filamentary or has sharp points or edges, and the other electrode has a smooth and extending surface, it is possible by impressing a high voltage across the electrodes to obtain ionization of the gases and cause any liquid or solid particles suspended therein to be precipitated upon the electrode with the smooth surface.

"An example of such apparatus is a smooth pipe having a fine wire held axially in, but insulated from, the pipe. The pipe is connected electrically to ground and the wire is connected to a source of high-tension current. The gases to be treated pass through the pipe and as they pass between the discharge and collecting electrodes they act as part of the electric circuit, the ions made in the gases acting as carriers of electricity from one electrode to the other.

"For electrical precipitation work, direct current is found to give much better results than alternating current, and the best results are secured when the ionizing or so-called discharge electrode is of negative polarity. It is possible, by making the electric field around the ionizing electrode very intense, to keep particles from being deposited upon it, and practically all the suspended material is deposited upon the smooth or collecting electrode which has an extended surface, the adjacent electric field being relatively weak.

"This characteristic of the particles to migrate towards the weakest part of the field may be explained in part by the phenomenon commonly called 'electric wind.' The molecules of the gases which have become ionized and the suspended particles to which electric charges are attached are propelled rapidly through the gases by the force of the electric field. The movement of these particles and molecules has an aspirating effect upon adjacent gas molecules, setting them in motion—the direction being from the strongest to the weakest part of the field. Charges of both positive and negative sign are present in the gases and they tend to move in opposite directions, but those which tend to move counter-current to the electric wind have to overcome considerable resistance and are probably swept back or neutralized, especially if these charges are endeavoring to take with them suspended particles. By making the central electrode of negative polarity the movement of the gases is set up by electrons and negative ions which have a higher velocity than positive ions, and the results described above are then the most pronounced and most satisfactory."

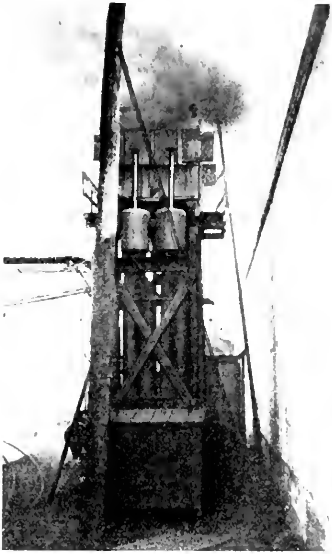
Plate Type of Precipitator

In practice, the precipitator, or "treater," may assume any one of several forms. The original Selby treater consisted of a lead-lined flue, four feet by four feet in section; the collecting electrodes were lead strips, four inches wide and four feet long, spaced about four inches from each other. Between each pair of collecting electrodes was a discharge electrode, consisting of a lead-covered iron pipe. As a comparatively low potential (17,000 volts) was used, it proved necessary to provide a large number of sharp points on each discharge electrode in order to obtain sufficient corona discharge. It was discovered that either asbestos cord or small pieces of mica, fastened to the electrode, served the purpose. These materials were made sufficiently conductive by the moisture present in the gases, and the sharp points of the mica, and fiber ends on the cord, made excellent discharge points.

The "plate" or "box" type of treater is usually a rectangular box or section of flue, in which the electrodes are placed. The collecting electrodes are ordinarily iron or steel plates, corrugated to give them stiffness sufficient to maintain the desired spacing accurately. This spacing is determined by conditions peculiar to the individual plant, such as the nature of the gas and fume, and is usually from 6 to 15 inches. The plates are of course electrically grounded. The discharge electrodes may be wires or chains suspended from an insulated framework so that they hang midway between the pairs of plates. The spacing between adjacent discharge electrodes in the same row is ordinarily about one half or one third of the distance between adjacent plates. The chains or wires are kept taut by weights suspended on their lower ends; often a pipe or channel-iron framework is also suspended on the discharge electrodes, the wires or chains passing through small holes in it. Such an arrangement helps to limit the swaying of the individual electrodes, and if it is guyed to the wall of the treater, through suitable insulators, acts as an efficient preventive of this swinging, which may otherwise interfere with the operation of the treater.

The writer has seen instances in the operation of a treater, in which the framework at the bottom of the discharge electrodes was not stayed, when arcing between the discharge and collecting electrodes would start the discharge electrodes swinging, and gradually increase the amplitude to such a degree that the voltage would have to be lowered very materially until the swinging stopped. This of course reduced the efficiency of precipitation. The only explanation that occurs for this phenomenon is that since the arc-over usually took place some distance below the top of the discharge electrode, there was a repulsive force exerted between the arc current in the discharge electrode and that in the plate. While this force undoubtedly was very small, as the arc current was usually less than one ampere, it was apparently sufficient to give the system of discharge electrodes a slight motion away from the plate to which the arc took place. Then on the return swing another arc would occur, giving the system another push, and so the action was rapidly cumulative.

In some plate treaters the gas enters at one of the sides to which the plates are perpendicular, and leaves at the other. Again, it may enter beneath the plates and leave above them. In any case the gas flow is parallel with the surfaces of the plates. Dampers are usually provided in both inlet and outlet, so that the distribution of the gas



CURRENT OFF

CURRENT ON

Figs. 1 and 2. Comparison Showing the Effectiveness of an Electrical Percipitator in Eliminating Coal Smoke

through the treater can be controlled within limits, or the gas flow stopped.

The International Smelting Company, at Tooele, Utah, is using a plate treater which is novel in that it is built simply as a section of the flue. The gas passes through four treater sections in series, each section being about 10 feet long. This gives an effective length of 40 feet, so that a fairly high gas velocity (15 to 20 feet per second) can be used. The plates are of the standard corrugated type, but the discharge electrodes are ¼-in. iron pipes, placed horizontally and supported between treater sections by grids of 1½-in. pipe which rest on suitable insulators. The horizontal arrangement of discharge electrodes eliminates the necessity for large spaces above and below the plates, in which to place the electrode supports.

The plate type of treater is one of the most economical in first cost, but it is somewhat difficult to secure and maintain uniform spacing between the plates and wires, as the plates naturally tend to warp out of shape as their temperature changes with varying gas conditions. Obviously, the arc-over voltage is determined by the minimum distance between electrodes at any point in the treater, so that any deviation from a uniform spacing will lower the maximum operating voltage and consequently the efficiency of precipitation.

Pipe Type of Precipitator

Another widely used type is the pipe or tube precipitator. In this the collecting electrodes are pipes, usually of steel, from 6 to 18 inches in diameter and from 10 to 20 feet in length. They are mounted vertically, a group of pipes forming each treater unit. Wire discharge electrodes are suspended from an insulated framework, so that one hangs along the axis of each tube. The same arrangement for staying the bottom ends of the wires is adopted as in the plate treaters. In a treater of this type care must be exercised in the manufacture and erection of the pipes to prevent any unevenness or bending which might affect the uniformity of the spacing between wires and pipes. An experimental pipe form of precipitator is shown in Figs. 1 and 2, and a commercial installation of a similar type of precipitator in Fig. 3.

Collection Electrodes

Precipitator collection electrodes are usually of steel. However, other materials are used, such as lead, if the gases contain corrosive agents. Even tile or masonry may be used if the upper surface is covered with a conducting film of moisture, as is the case in the collection of sulphuric acid mist.

Discharge Electrodes

The most common type of discharge electrode is a steel or copper wire about $\frac{1}{16}$ in. in diameter. Small steel chains are also employed. In Dr. Cottrell's early work relatively low voltages were employed, and it was necessary to provide innumerable sharp points or edges on the discharge electrodes in order to facilitate the corona discharge. However, with the voltages now employed, such steps are unnecessary, ample discharge being obtained from an ordinary wire or pipe.

Fig. 3. Cement Dust Precipitator, Alpha Portland Cement Co., Cementon, N. Y.

Insulation of Discharge Electrodes

In all types of treaters, the insulation of the framework which supports the discharge electrodes is somewhat of a problem. This is especially the case when the gases are at a high temperature, or contain moisture or corrosive agents. It is general practice to extend the end members of the framework, through openings in the precipitator walls, into small chambers in which the supporting insulators are placed. These housings are fitted with doors so that the insulators are readily accessible for cleaning or repairs.

This arrangement removes the insulator from the path of the main gas stream, but sometimes causes trouble due to the fact that the temperature of the insulator is usually less than that of the gas in the treater, and consequently moisture may condense on it. However, if the system operates under draft from a stack, or from a fan beyond the treater, the gas pressure inside the treater and insulator housing will be less than that of the atmosphere, so that provision in the housing of a small opening to the air will cause a stream of air to flow through the housing into the treater, thus helping to prevent the deposition of dust and moisture on the insulators.

The insulators employed are of various types, one being a porcelain post with the usual corrugated surface. In some installations each insulator is composed of a pile of slabs of Catalina marble. Slabs of two different sizes are placed alternately in the pile to increase the creepage surface along the insulator. In one plant slabs of ordinary fire clay were used with some success. The type of insulator that will give the most satisfactory service will depend on the nature and temperature of the gas, and other conditions.

Removal of Collected Dust

The methods adopted to remove the collected dust from the electrodes vary, the general scheme being to rap the pipes or plates with a series of hammers which may all be actuated from a common lever or by a motor. As a certain amount of dust collects on the wires or chains, some arrangement is required for rapping or vibrating the insulated framework from which these electrodes are suspended. While the treater is being rapped its dampers are closed to shut off the gas flow through it, and it is disconnected from the power supply. Obviously, if the gas flow were not stopped, a large proportion of the dislodged dust would be carried in the gas stream through the treater and out the stack. Hoppers are located beneath the electrodes at a distance sufficient to prevent the dust in them from being disturbed by the gas stream. The dust falls into these hoppers from which it may be removed at suitable intervals. In some instances conveyors are used to remove the dust from the hoppers continuously.

The length of time between rappings depends upon the operating conditions, and usually varies from two to ten hours. A clean precipitator will usually give more efficient precipitation than a dirty one. As the dust collects on the discharge electrodes, the effective diameter of these electrodes increases thereby decreasing the amount of corona discharge, which is so necessary to effective operation.

Installation Features of Precipitator

The treater proper is usually installed some distance above the ground in order to allow room for the dust hoppers and flues beneath it. In pipe treaters the gas may be led in either at the bottom or top of the pipes. As a general rule, more uniform gas distribution among the various pipes of a unit will be obtained if the gas is led in at the top and down through the tubes. This is especially true with hot gases, as the inner pipes in a bank will naturally lose less heat by radiation than the outer and consequently the up-draft in the inner tubes will be stronger. As a result, if the normal gas flow is upward, the gas velocity in the inner pipes will be greater than in the outer. Occasionally, in order to correct such conditions, the whole precipitator is enclosed in a housing of brick or other material.

In any precipitator installation means must be provided for by-passing the gas around any treater unit while that unit is being cleaned or repaired. This requires dampers in the flue at the inlet and outlet of each unit, and, if the plant consists of only a single unit, a by-pass flue. If there are two or more units the dampers on one can be closed, forcing all the gas through the others while the first one is being cleaned. The cleaning operation requires only a few minutes so that such action will not cause any great loss of dust.

Size of Precipitator

The size of a given precipitator installation is of course determined by the volume of gas to be treated. The gas velocity in the treater itself usually does not exceed ten feet per second and often is only five to seven feet. If higher gas velocities are used, the efficiency of the precipitator is decreased unless the path of the gas through the precipitator is lengthened or the spacing between electrodes decreased. The reason for this is evident, when it is considered that every material particle in the gas stream through the treater has two forces acting on it: one in a direction parallel to the electrodes, due to the velocity of the gas; and one perpendicular to the electrodes, due to the electrostatic field. The motion of the particle will be due to the resultant of these forces. Now if the velocity of the gas is too high, a particle entering the precipitator near the discharge electrode may take a path which gradually approaches the collecting electrode, but will not reach it before it is carried beyond the treater. Consequently it is of extreme importance, not only that the average gas velocity in the precipitator be kept at a low value, but also that the velocity, or gas distribution, in all parts of the treater be uniform.

Subdivision of Precipitator Installation

Almost all precipitator installations are divided into several units or treaters, usually with individual electrical equipment. That is, if a given plant requires a total of 400 tubes or pipes to handle the gas, the installation may consist of four treaters of 100 pipes each, a portion of the gas passing through each treater.

There are several reasons for this practice. Probably the most important one is that the gas flow through a treater must be stopped while the electrodes are being cleaned. Obviously, the larger the number of treaters the smaller will be the decrease in efficiency, due to overloading, when one treater is closed for cleaning or repairs. Furthermore, in a very large treater it would be difficult to get uniform gas distribution, unless it were divided into sections each equipped with dampers. This would amount to the same thing as a number of treater units.

A third reason lies in the fact that, for a given treater, better precipitation is obtained as the operating voltage is increased, since of course the electrostatic field is stronger. As a consequence, it is desirable to operate at a voltage just below that which will cause arcing in the treater. Now the arc-over voltage will be determined by the minimum spacing between electrodes at any point. Consequently, if any one plate, tube, or wire is bent or distorted so that the spacing is reduced below the normal value, the operating voltage on the entire treater must be reduced. If this defective treater constitutes a large portion of the entire plant, the overall efficiency of the plant will be reduced more than if it is only a small section. This feature also constitutes an argument against operating two or more treaters electrically in multiple on one electrical equipment, for if one treater is defective the voltage on both must be lowered.

Type of Current and Values of Voltage Employed in Precipitator

All Cottrell precipitators use a high-voltage unidirectional current. If alternating current were used it is obvious that the dust particles would receive an impulse toward one electrode during one half cycle, and toward the other during the other half cycle. This would result in very little precipitation on the electrodes, although it would tend to cause the particles to agglomerate, and some of the agglomerated masses would settle out of the gas stream, thus causing a certain amount of cleaning. It has been found that better operation is obtained with negative corona than with positive, that is, when the discharge electrode is made negative and the collecting or grounded electrode positive. With negative corona a higher voltage can be carried without arcing than with positive, and the operation is in general smoother and more efficient.

The voltage employed ranges from 25,000 to 100,000. Some years ago the tendency was toward very high voltages, and it was predicted that 250,000 volts would be used. However, with such high voltages the insulation difficulties increase tremendously, with no commensurate gain, so that at present the majority of plants operate at from 50,000 to 75,000 volts, and few installations are now being made to operate at higher voltages.

Power Required

The amount of power required by a precipitator varies with the composition and temperature of the gas, and with other conditions, so it is impossible to give a value which will be accurate for all cases. An average figure is perhaps 2 kw. input for each 10,000 cubic feet of gas treated per minute, although in some plants the power requirements are much lower. Since each treater unit is of comparatively small size and each usually has an individual electrical unit, the electrical sets themselves are of relatively small capacity. There are very few plants which have electrical units of more than 25 kv-a. each. The largest in operation are 75 kv-a. each, and by far the majority are of 10 or 15 kv-a. capacity.

Means of Securing Suitable Energy for Precipitator

In all cases, the high unidirectional voltage is obtained by stepping up a single-phase, alternating, low voltage through a special transformer, and rectifying it by means of a mechanical or vacuum-tube rectifier. Two general systems are in use for obtaining the single-phase low-voltage power. One involves a small motor-driven generator, usually a separate motor-generator set being used

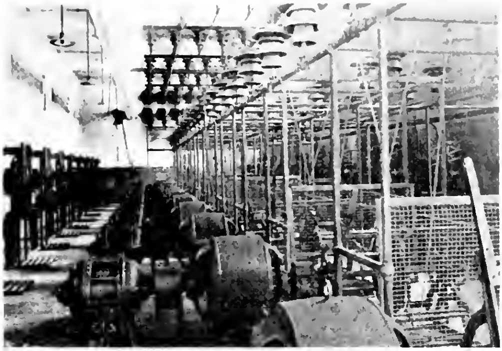


Fig. 4. A Portion of the Electrical Equipment for a Large Cement Dust Precipitator Installation

with each transformer as shown in Fig. 4. This arrangement affords a ready means of adjusting the treater voltage for varying gas conditions, by merely changing the generator field excitation, and the mechanical rectifier can be directly coupled to the shaft of the motor-generator set. In the second system power is taken directly from one phase of an available low-voltage circuit, the treater voltage adjustment being obtained by means of taps on the transformer low-voltage winding together with an induction regulator or a regulating rheostat in the low-voltage circuit to obtain close adjustment. For small installations the rheostat is satisfactory, but for large units the power losses in such a resistance are considerable and the use of the induction regulator is advisable. With the second arrangement a small synchronous motor is required for driving the mechanical rectifier.

When there is available a low-voltage alternating-current supply circuit, satisfactory operation can be obtained without the use of a motor-generator set provided the voltage of the circuit is reasonably constant. Obviously, if the supply voltage varies greatly it will be impossible to hold the treater voltage at the value necessary for most efficient precipitation. Under such conditions, or when only direct current is obtainable, the motor-driven generator must be used. Naturally, the first cost of the electrical equipment is greater when the motor-generator set is employed. However, since the investment in electrical apparatus is rarely more than ten per cent of the total cost of a precipitator installation, the difference in total investment, whether a motor-generator is or is not included, is hardly appreciable.

Motor-generator

The motor-generator set is illustrated in Fig. 5, and consists ordinarily of a single-phase four-pole 220-volt 60-cycle generator, driven by either an alternating-current or direct-current motor, depending on the available power supply. The generator is often so designed that its armature voltage may be varied from 110 to 250 by adjusting the field rheostat. This gives very flexible control of the treater voltage. It is always a four-pole machine, for as will be evident from an inspection of the illustration of the mechanical rectifier, Fig. 9, and of the diagram of connections of a mechanical rectifier equipment, Fig. 10, the rectifier must rotate at a speed corresponding to that of a four-pole machine. A shaft extension is provided for coupling to the mechanical rectifier.

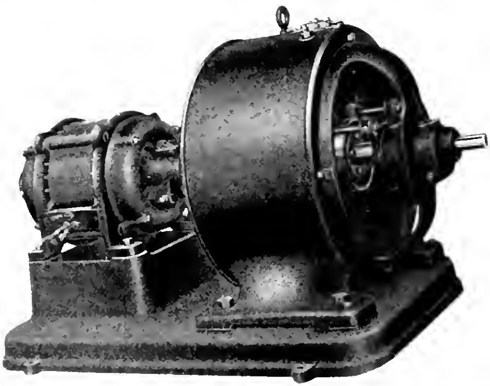


Fig. 5. Motor-Generator Set for Obtaining High-voltage Unidirectional Precipitation Current

If no direct current is available for excitation of the generator field, an exciter set must be included in the installation.

Synchronous Motor

In case the motor-generator set is omitted and power is taken direct from an alternating-current supply circuit, if a mechanical rectifier is used a small synchronous motor, Fig. 6, must be employed to drive it. For this purpose, motors requiring no direct-current field excitation have been developed. These motors are really squirrel-cage type induction motors having rotors especially slotted to form salient poles. Such a motor starts as an induction motor, but operates at synchronous speed provided it is not loaded too heavily. The power-factor is of course low, approximately 30 to 50 per cent. As one horse power or less is sufficient to drive the rectifier, these motors are highly satisfactory for the purpose. They are built to operate on either single-phase or polyphase power at any standard low voltage and frequency.

Transformer and Its Protection

The transformer is the most vital part of the electrical equipment, and is subjected to extremely severe service. Since the rectifier merely rectifies the middle portion, or top, of the voltage wave, the high-voltage circuit is made and broken once every half cycle with an arc at each make and break. Furthermore, the construction of the rectifier is such that the rotating points never make actual contact with the stationary shoes, so there are always four arcs in series in the circuit. As the treater has some electrostatic capacity and the transformer a certain amount of inductance, conditions may arise which cause very high voltages in the circuit, particularly in sections of the high-voltage winding of the transformer.

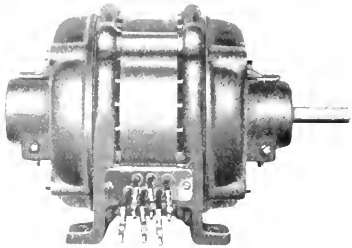


Fig 6. Self-excited Synchronous Motor for Driving Mechanical Rectifier

Consequently, extreme precautions are necessary in the design and building of the transformer, particularly of the high-voltage winding and terminals. The insulation between turns and between coils must be extraordinarily good, especially on the end coils. In precipitation transformers of General Electric manufacture the insulation *between turns* of the end coils is sufficient to withstand from 50 to 100 per cent of the full rated

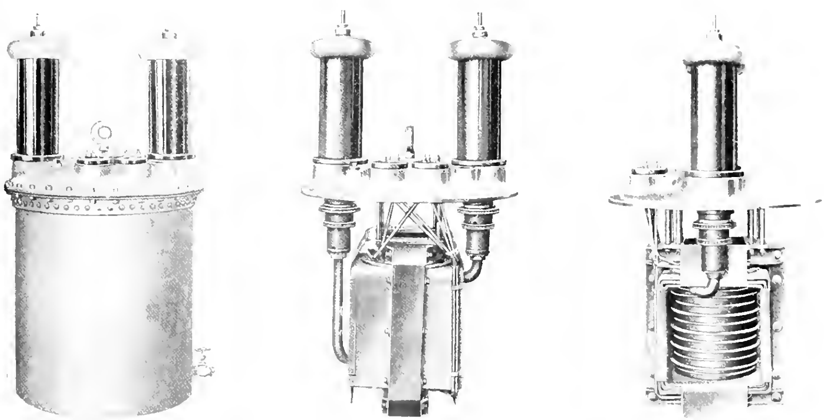


Fig. 7 External and Internal Views of 60-cycle, 10-kv-a., 100,000, 87,500 75,000 62,500/50,000-220-volt Precipitator Transformer

high voltage of the transformer. Three views of the transformer are shown in Fig. 7, and the extra heavy insulation is plainly visible.

It is an interesting fact that of the failures of precipitation transformers, of varied manufacture and of which the writer has knowledge,

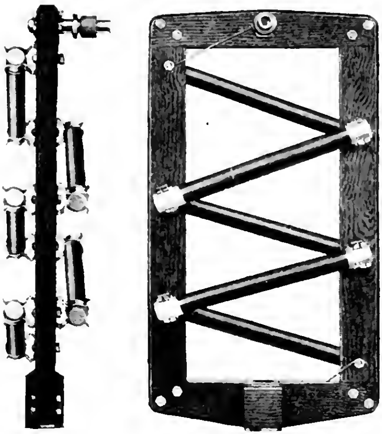


Fig. 8. Protective Resistance for Precipitator Transformer

all have been breakdowns in the insulation between turns or coils of the high-voltage winding, and not one from the high voltage to the low voltage or ground. This illustrates the futility of depending on an extremely high potential test to ground in order to insure a serviceable transformer. Even at 300 per cent normal voltage, the volts between turns would not ordinarily be over 30, whereas the insulation between turns, even at the weakest point, will withstand 2000 volts or more.

In order to protect the transformer so far as possible from high-voltage surges, it has been found advisable to adopt certain protective devices in the high-voltage circuit. These originally took the form of choke coils, or reactance coils, mounted on the transformer terminals. Such coils are still used to some extent. However, the General Electric Company after much experimental work has proved that resistors in the high-voltage circuit afford much better protection than choke coils. Fig. 8 illustrates a group of these resistors. While the amount of resistance used is high, the line current is small, and the voltage drop and power loss are correspondingly low. The resistors are rods very similar to those used in connection with lightning arresters.

The low-voltage winding of the transformer is often provided with taps to give various high-potential voltages such as 100,000/87,500/75,000/62,500/50,000, or 85,000/80,000/75,000/70,000/65,000.

Mechanical Rectifier

The construction of the mechanical rectifier can be easily understood from Fig. 9. The rotor is a disk of bakelite or similar material with two metallic strips each 90 mechanical degrees in length, mounted opposite each other on its circumference. Four stationary metallic shoes are supported on insulating rods as shown. The position of the structure which supports the shoes may be adjusted so that any portion of the alternating wave may be rectified or picked off.

In another type of rectifier the rotating element has four arms, each carrying a conducting point. Two adjacent points are connected by a steel wire, and the two opposite points are also connected together. The stationary member is similar to that of the disk rectifier.

Kenotron Rectifier

The kenotron, Fig. 11, a rectifier of the hot-cathode vacuum-tube type, has not been

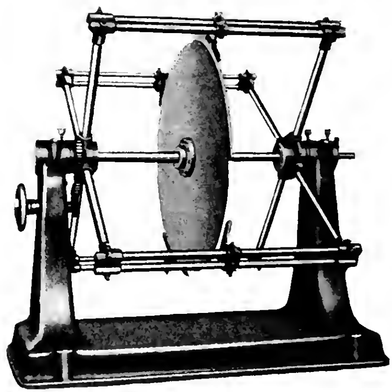


Fig. 9. "Lemp" Mechanical Rectifier for Potentials up to 100,000 Volts

extensively used in precipitation service, but preliminary tests show that it possesses certain advantages. As is evident from the oscillograms which are shown in Figs. 12 and 13, it gives a smoother rectified voltage wave, and this tends to give better precipitation as the average voltage is nearer the maximum value. Furthermore, the high-frequency peaks, present in the rectified current wave from the mechanical rectifier, are absent when the kenotron is used. This reduces the high-voltage stresses on the transformer and other equipment. The kenotron also shows a considerable gain in electrical efficiency over the mechanical rectifier equipment, especially when comparatively large currents (one half to one ampere) are rectified. It is of course noiseless, a pleasing contrast to the mechanical rectifier.

The one disadvantage of the kenotron is the fact that it has a limited life. After a certain amount of operation the hot cathode, or filament, "burns out," just as does an incandescent lamp filament. The life depends on the temperature at which the filament operates, which is in turn determined by the rectified current output desired. Commercial tubes are ordinarily operated at a filament

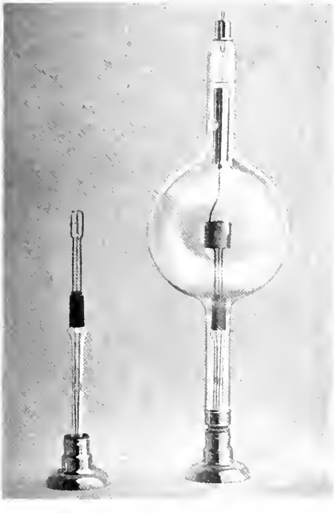


Fig. 11. Construction of the Kenotron Used in Place of the Mechanical Rectifier

temperature which will give a life of at least 2500 hours, and reasonable outputs can be obtained with temperatures low enough to give a life of 5000 or even 10,000 hours. However, it should be noted that when a filament does burn out, it can be renewed at a fraction of the cost of a new tube. Recent improvements in the constitution of the cathode give promise of a very material increase in life.

Remaining Equipment

A precipitation switchboard equipment includes the necessary circuit breakers, switches,

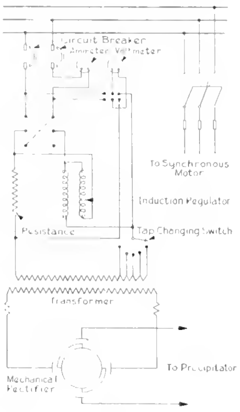


Fig. 10. Connection Diagram for Mechanical Rectifier Equipment

and instruments, and also a double-pole double-throw reversing switch in the low-voltage circuit of the transformer. By means of this reversing switch the direction of flow of the unidirectional current through the treater can be controlled, making it possible to insure negative corona on the discharge electrode.

In addition to the protective resistors on the transformer high-tension terminals, it is generally advisable to place similar resistance units in the high-tension lines between the rectifier and the treater. Smoother operation is obtained and the current surge in case of arc-over is limited by their use.

Field of Application

As to the field of application of the Cottrell process, it is evident that only material particles can be precipitated. That is, it is not possible to separate one gas from another, but only to remove dirt, fume, or mist particles from a gas. As has been mentioned, the first commercial application of the process was to the collection of sulphuric acid mist.

The next field which was attacked was the precipitation of fume and dust from the stack gases of copper and other smelters. It is claimed that the suspended matter carried in these gases works great damage on vegetation in the country surrounding the smelters, and

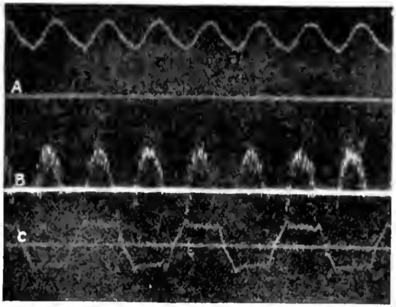


Fig. 12. Oscillogram of Smoke Precipitation Test with Mechanical Rectifier

A, Rectified Voltage; *B*, Rectified Current
C, Transformer Primary Voltage

there has been much litigation between smelters and farmers, some smelters being compelled to close down. Those that are operating have almost all been forced to adopt some scheme for cleaning the gases. Some have installed bag houses, in which the gas is forced through woolen bags, but these bag houses are expensive, cut down the draft, and the bags may be destroyed by acid fumes or high temperatures.

Very many smelting plants have adopted the Cottrell process as a means of cleaning their stack gases, with satisfactory results. Not only is the outgoing gas freed from the objectionable suspended matter, but this matter is as a rule rich in metal values, which are conserved. Obviously, a treater which every 24 hours collects ten tons of dust containing 3 to 8 per cent of copper besides lead, gold, silver, and arsenic will easily pay a good return on a considerable investment.

It is possible to obtain very pure arsenic trioxide from smelter fume by what is termed fractional precipitation. When the gases are at a temperature of 250 deg. C. or above, the arsenic content is in the form of a true gas so that the dust content may be precipitated without affecting the arsenic. If then, by passing the gas through a cooling flue, its temperature is lowered sufficiently, the arsenic will separate out as a cloud of fume which may be collected in a second treater.

Portland cement manufacturers have also encountered trouble with farmers near their plants, due to the dust carried out in the gases settling on the surrounding country. A number of such plants have installed Cottrell precipitators with excellent results. Here also the recovered dust is usually valuable, containing a considerable amount of potash.

While smelters and cement plants use the majority of the precipitators now installed, there are many other applications. Among these may be mentioned the detarring and cleaning of illuminating gas; the collection of powdered foods manufactured by the spraying process; the collection of phosphoric acid from the gases from furnaces smelting phosphate rock; the cleaning of blast furnace gases; the precipitation of coal smoke, and others.

The application of the process to blast furnace gases is progressing rather slowly, owing to difficulties due to the high temperature and explosive nature of the gas, and other causes. This, however, should prove a fertile field as the advantages of dry cleaning the gas, as compared to present methods, are obvious.

Very few installations for treating coal smoke have been made. While coal smoke is

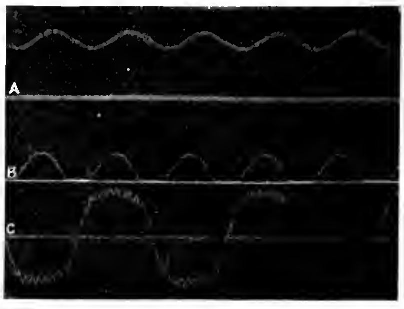


Fig. 13. Oscillogram of Smoke Precipitation Test with Four Kenotrons

A, Rectified Voltage; *B*, Rectified Current
C, Primary Voltage

objectionable, it does not of course cause the devastation alleged against smelter fumes. Furthermore, the material recovered from coal smoke has little if any value so that all that is gained by the use of the precipitator is the mitigation of a nuisance, and there is little return on the money invested. Consequently there seems little prospect of the extension of the process to coal smoke. The solution of this problem lies rather in burning the coal under conditions which minimize the smoke.

It is evident that the Cottrell process is performing an important service in the prevention of waste, and the elimination of damage to vegetation, including forests. It is also being used as an important step in industrial processes, as in the production of phosphoric acid, and the chloride volatilization process of ore reduction. In the short time since Dr. Cottrell began his experiments, it has assumed an important place in our economic life and undoubtedly its use and importance will continue to increase.

Adjustable Varying Speed Alternating-current Commutator Motors

By R. A. Jones

Power and Mining Engineering Department, General Electric Company

This article discusses the polyphase a-c. brush-shifting motor for the benefit of the engineer or user who wishes to make a selection of a motor for a particular service, and it deals principally with the operating characteristics of the motor and the methods of speed control. For those applications where the brush-shifting a-c. commutator motor may be used the choice usually lies between this motor and the slip ring polyphase induction motor, and the author has therefore drawn a comparison between the performances of these two types The advantages of the brush-shifting motor are conspicuous in almost all respects. The single-phase brush-shifting motor also has wide application in industry and a brief description of the theory, control and application of this motor is included.—Editor.

INTRODUCTION

Alternating-current commutator motors were known before the polyphase induction motors found their enormous application; but because of inherent troubles from commutator wear and sparking at the brushes they found no commercial field of usefulness. The advent of the induction motor turned attention from the commutator motor, and a number of years elapsed before the latter type of motor received any further consideration.

The growing demand in the last ten or fifteen years for an alternating-current motor having speed regulation over a wide range with small increments, and without the considerable loss of energy involved in the use of the induction motor having polar wound armature and secondary resistance control, led to the development of the adjustable varying speed, brush shifting, single-phase and polyphase motors having series characteristics.

POLYPHASE ALTERNATING-CURRENT SERIES BRUSH-SHIFTING MOTORS

General Theory of Operation

A detailed development of the theory of the type BTS and BQS motors is given in the February, 1916, General Electric Review. An abbreviated explanation is given in the issue of September, 1921, pages 804 and 805.

In addition to inherently providing the necessary flux for counteracting the induced commutation voltage, polyphase machines have a further advantage in the possibility of increasing the number of phases in the rotor. This may be explained by comparison with the direct-current and alternating-current single-phase series motors. It is evident that with a direct-current or single-phase machine the change of direction of the current when the rotor coil is passing under the brushes is

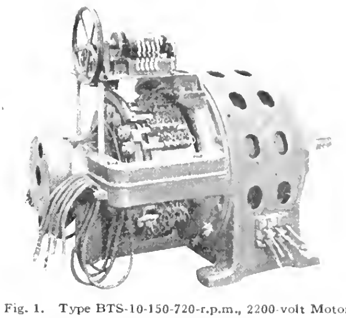


Fig. 1. Type BTS-10-150-720-r.p.m., 2200-volt Motors with Master Switch (cover removed) and Pilot Motor for Automatic Brush-shifting Control Actuated by Air Pressure or Push Button

180 deg. With a 3-phase rotor this is reduced to 120 deg., 6-phase to 60 deg., and 12-phase to 30 deg. Assuming that this voltage equals unity for a single-phase machine, then for the 6-phase rotor it will be reduced to *sin* $60°/2$ or 0.43. Increasing the rotor phases also provides additional circuits for the rotor current and decreases the current per brush stud.

It is also a fact that the interaction of the fluxes of the different phases is such that a voltage is produced in the armature which tends to improve the power-factor. Polyphase motors can be designed to operate at full load and synchronous speed with leading current.

Construction

In actual construction the motor consists of a stationary member or stator, and a rotating member or rotor, and a transformer connecting the rotor in series with the stator.

The stator has a distributed winding and is similar to that of the ordinary induction motor. The stator of an induction motor having the same number of poles, horsepower, voltage and frequency can be used without change for numerous ratings.

The rotor is in appearance and design essentially like that of a direct-current motor or generator, except that the armature voltage is considerably lower.

The rotor transformer is simply a series transformer with the primary in series with the stator of the motor and the secondary connected to the rotor through the brushes and commutator. This transformer not only supplies a lower commutator voltage, but by its ability to become saturated limits the no load speed of the motor to a safe value. This limit is approximately 150 per cent speed.

A general understanding of the action of the transformer saturation in limiting the maximum speed can be obtained by thinking of the motor rotor as the rotor of a slip ring induction motor. As the speed varies from synchronism the voltage across the rings increases. This increases the counter e.m.f. opposing the secondary voltage of the rotor transformer. Therefore, unless the transformer secondary voltage increases, the current and torque decrease with a corresponding reduction in speed. Since the maximum transformer secondary voltage is limited by the transformer saturation the speed is limited.

The influence of frequency upon the dimensions of the commutators of these machines may be shown by comparing a 24-pole, 300-r.p.m., 60-cycle motor with a 10-pole 300-r.p.m., 25-cycle motor. The synchronous speed of the two being the same, they may be equipped with commutators of the same diameter and same number of bars. If the 10-pole, 25-cycle motor is designed with 2.4 (that is 60/25) times the flux of the 24-pole, 60-cycle motor, then at half speed the voltage between bars and the commutation conditions will be identical. On the 10-pole motor, between two brush studs spanning a full pole pitch, there will be 2.4 times as many commutator bars as on the 24-pole motor, giving 2.4 times the secondary voltage of the 24-pole, 60-cycle motor. Since the number of rotor phases may be increased, and since the full number of brush studs equals the number of pairs of poles times the rotor phases, the secondary of the transformer for the 10-pole motor may be designed with 2.4 times the number of phases and the same number of brush studs. This increase in the number of phases of the 10-pole motor rotor decreases the current per phase for the same output, and therefore increases the capacity of the

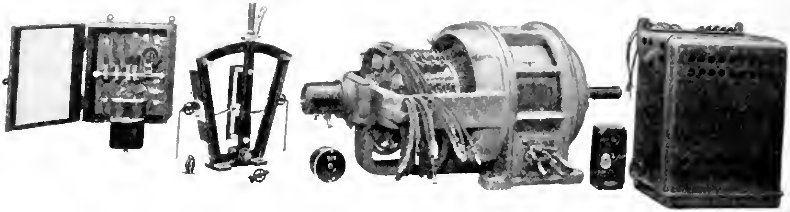


Fig. 2. Type BTS 25-h.p., 1200-r.p.m., 550-volt Motor with Semi-automatic Control Accessories for Constant Torque Applications Such as Textile Mill Machines

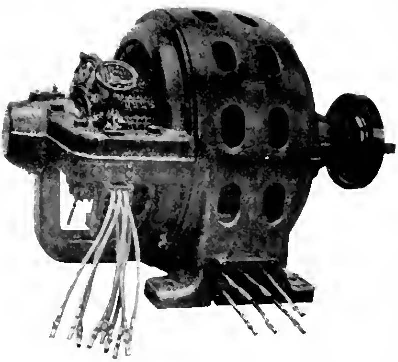


Fig. 3. Type BTS 300-h.p., 750-r.p.m., 550-volt Motor with Worm and Hand Wheel for Shifting the Brushes

commutator in the same ratio. For this reason 25-cycle circuits are better adapted for polyphase motors than circuits of higher frequency.

With motors having a large number of poles it is often desirable to eliminate some of the brush studs, by equalizing the commutator bars and allowing one stud to carry the current of two or more.

Rating

The standard polyphase motors are built in capacities of 5 to 40 h.p., 1200 r.p.m., 220, 440 and 550 volts, and are continuous rated on the basis of constant horsepower output at speeds from 1200 to 1350 r.p.m., constant torque from 1200 to 600 r.p.m. In addition the motors are given an intermittent rating for constant torque covering speeds from 600 to 450 r.p.m. Fig. 2 illustrates a standard 25-h.p. motor with control. Fig. 3 illustrates a 300-h.p. motor. These motors are called type BTS for 3-phase and BQS for quarter-phase.

The maximum capacity for which these motors can be built is limited by commutating conditions. It has been found by experience that a limit of 30 h.p. per pole for 60-cycle motors, and 70 h.p. per pole for 25-cycle motors may be used for rough approximations. This rule of thumb gives a limit of

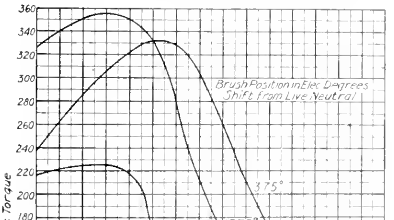


Fig. 4. Typical Speed-torque Curves of the Brush-shifting Motor for Various Positions of the Brushes

about 175 h.p. for 1200-r.p.m. motors and 350 h.p. for 600-r.p.m. motors.

Speed Torque

The speed-torque curves of Fig. 4 show that the characteristics of this motor compare favorably with those of slip ring induction motors having secondary resistance control (Fig. 5). Wherever a slip ring induction motor is applicable for adjustable varying speed service the brush lifting motor may be applied, and in addition to having

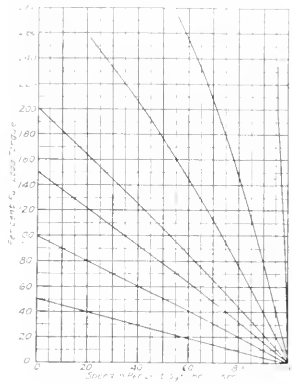


Fig. 5. Slip Ring Motor Speed-torque Curves with Various Amounts of Resistance in the Rotor Circuit

similar series characteristics it provides an infinite number of speed points. At extremely low speeds the available torque decreases, and for constant torque duty a minimum speed limit device is required for protection against stalling. The tripping point of this device may be adjusted to suit the load.

Where constant torque is required over a speed range greater than that provided by the standard design (3 to 1) a larger motor and rotor transformer are necessary. In general the lower limit for loads having more or less constant torque is about 65 to 75 per cent below synchronous speed.

For centrifugal pumps, fans, etc., where the torque decreases rapidly with the speed, stable conditions exist at all speeds practically down to standstill. Fig. 6 (solid curves) shows the characteristics of a BTS 150-h.p. 450-r.p.m. motor with stator connected delta. By arranging the motor line switches so that the stator connections can be readily changed from delta to Y, which is equivalent to reducing the voltage, the low speed torque characteristics will be practically the same as shown by the dotted curves, but the efficiency and power factor will be greatly improved as will be shown later. This delta-Y change is used only for drives where the torque decreases rapidly with the speed.

Still referring to Fig. 6, it will be seen that the brush shift in electrical degrees corresponding to each curve is indicated and that for the same brush position the motor has a lower speed with the Y connection than with the delta connection. Consequently, in order to obtain a smooth speed curve, it is necessary to shift the brushes to compensate for the effect of the delta-Y change in the stator connections.

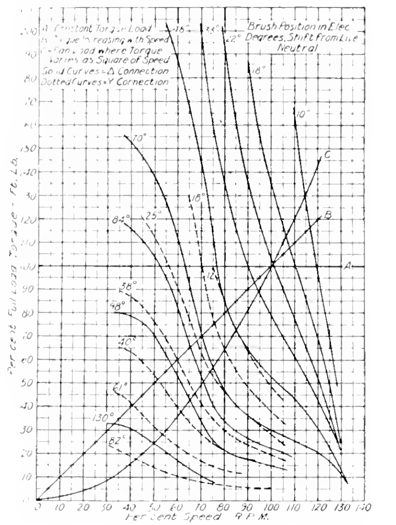


Fig. 6. Brush-shifting Motor Speed-torque Curves for Various Brush Positions with Both Delta and Y-connected Stator

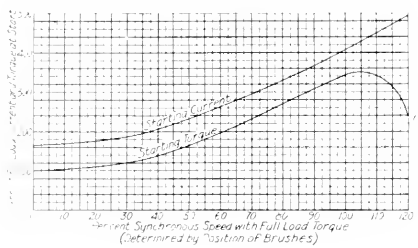


Fig. 7. Brush-shifting Motor Starting Characteristics

Starting Current and Torque

The starting current and torque at different brush positions are shown in Fig. 7. With the brushes set to give full load torque at standstill the inrush current will be 164 per cent of the normal full load current. If the motor were started up with the brushes set in the position to give 50 per cent speed at full load torque, the starting torque would be 164 per cent and the current 232 per cent. These curves are based on the 10-h.p. 1200-r.p.m. motor with the stator delta-connected and will not apply specifically to other ratings since the degree of brush shift for a certain speed varies for different motors. However, they illustrate the general relationship between starting torque and current and show that the starting torque may be varied within the maximum torque limits, merely by shifting the brushes. Another desirable feature is the ability to accelerate as slowly or as rapidly as desired, by slowly or rapidly moving the brushes from the slow speed position.

Efficiency and Power Factor

Typical comparative efficiency and power factor curves for BTS and slip ring motors when driving a fan load or similar loads such as pumps are given by Fig. 8. One hundred per cent speed for the BTS motor is equal to $12\frac{1}{2}$ per cent above synchronism, while for the induction motor it equals full load speed, which is approximately 96 per cent of synchronism. This comparison assumes that the motors are driving equal loads but that the machine for the slip ring motor is designed for a slightly lower speed. At 100 per cent speed the slip ring motor efficiency is slightly higher, but as the speed decreases the loss in the secondary resistors causes the efficiency to drop off rapidly.

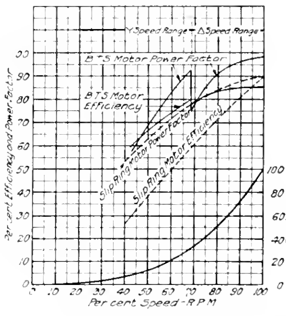


Fig. 8. Typical Comparative Efficiency and Power Factor Curves of BTS and Slip Ring Motors Under Fan Load

The break in the curves is due to changing the motor connections from delta to Y. Changing to the Y-connection is equivalent to a voltage reduction, and, as is evidenced by the great increase in power factor, results in decreasing the magnetizing current. In most cases, for loads of this kind the change-over point should be at about 70 per cent speed. When this change is made a different speed is obtained for the same brush setting.

The benefit of this higher efficiency is more clearly shown by Fig. 9 which gives the comparative kilowatt input per horsepower when operating at different speeds. The saving in kilowatt input per horsepower by using the BTS motor instead of the slip ring induction motor is also shown. If the motors in question are 100 h.p. the kilowatt saving (Fig. 9) at 75 per cent speed will equal 100×0.091, or or 9.1 kilowatts. The saving per year at this speed, assuming 365 twenty-four hour days (8760 hrs.), will be 79,700 kw-hrs.

By estimating in detail the operating speed cycle that is required a more representative power saving may be calculated as follows: Assume a 100-h.p. fan unit having a speed cycle of operation each day equivalent to:

4 hours run at 100 per cent speed
8 hours run at 85 per cent speed
8 hours run at 65 per cent speed
4 hours run at 50 per cent speed

From Fig. 9:

Hours	Per Cent Speed		Kw-hrs.
4	–100	=4×100×.045 =	18.0 loss
8	– 85	=8×100×.058 =	46.4 saving
8	– 65	=8×100×.102 =	81.6 saving
4	– 50	=4×100×.095 =	38.0 saving

Total kw-hrs. saved per day .... = 148.0
Total kw-hrs. saved per year (365 days) .... = 54000

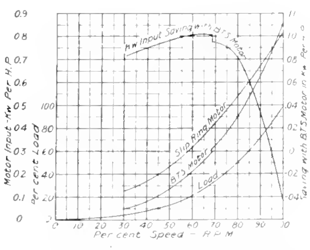


Fig. 9. Comparative Kilowatt Input Per Horsepower for BTS Motors and Slip Ring Motors Driving a Fan Load

At one cent per kw-hr. this equals a saving of $540 per year, which, capitalized at 15 per cent for interest and depreciation, etc., justifies an additional expenditure of $3600 for the BTS equipment. This is a conservative estimate, for in the majority of cases the cost of power exceeds one cent per kw-hr.; but even so the additional expenditure that is justified would practically cover the complete charge for a new motor and therefore warrant the use of the BTS equipment even

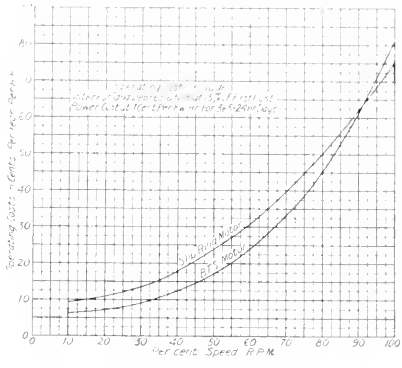


Fig. 10. Comparative Operating Costs for BTS Motors and Slip Ring Motors as Affected by the Operating Speed

though the slip ring motor could be obtained for nothing.

The importance of this increased efficiency for varying speed, fan drive or similar drives is further illustrated by Fig. 10, where the operating cost per horsepower per year is plotted against speed. This operating cost includes interest on the capital investment and depreciation at 15 per cent, and a power charge of one cent per kw-hr. input. This shows that above 91½ per cent speed the BTS motor is generally the more expensive, but for operation at any speed below this it is by far the cheaper equipment. Assume for example a 100-h.p. motor operating continuously at 70 per cent speed: The operating cost per horsepower per year for the slip ring motor is $39.60 and for the BTS motor $33.50. Therefore, with a 100-h.p. motor there would be a saving of $610 per year and at the end of 6 years the BTS motor would have paid for itself.

For loads requiring constant torque throughout the entire speed range the BTS motor is even more desirable, as is shown by the curves of Figs. 11 and 12. At 70 per cent speed (Fig. 12) the saving is 0.2 kw. per horsepower as compared with 0.092 kw. per horsepower with a fan load (Fig. 9). It will be noted that with a slip ring motor driving a constant torque load the input remains constant for all speeds, while the horsepower output decreases directly with the speed.

Fig. 13 compares a BTS motor with a direct-current motor whose speed is varied by adjusting the field. The efficiency of the direct-current motor is higher through most

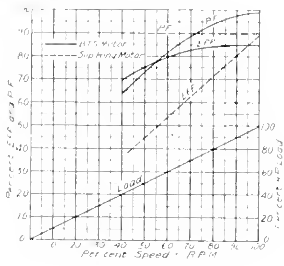


Fig. 11. Comparative Efficiency and Power Factor of BTS Motors and Slip Ring Motors Driving Constant Torque Loads

of the speed range; however, if it were necessary to install a motor-generator set or converter for supplying direct current the efficiency would be in favor of the BTS motor.

Control

The control actually required for operating this type of motor is extremely simple, consisting merely of a switch for connecting the

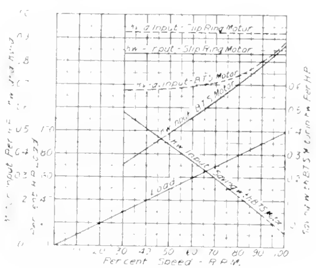


Fig 12. Comparative Kilowatt and Kilovolt Input Per Horse Power for BTS Motors and Slip Ring Motors Driving a Constant Torque Load

motor stator to the line and some mechanical means of shifting the brushes.

Semi-automatic Control

For the standard line of motors (5 to 40 h.p. inclusive) designed for textile mill or similar drives requiring constant torque over a 3 to 1 speed range the "semi-automatic control" is used. This control, as illustrated in Fig. 2, consists of:

1 Enclosed contactor with inverse time limit overload relays and undervoltage release.
1 Start, stop and jog push button station.
1 Stop button.

(The jog button and auxiliary stop button are especially for textile mill applications and are usually replaced by a start and stop station for other services.)

1 Brush-shifting controller with chain and guide pulleys for providing mechanical speed control at the driven machine. For motors larger than 40 h.p. mechanical brush shift is obtained by a hand wheel and worm gear mounted upon the motor end shield and brush rigging. The rotor transformer and motor are also shown in Fig. 2.

Hand Control

For fan or centrifugal pump drive, or similar drives where the torque decreases with the speed hand control is especially applicable since it provides for the Y-delta change in the connections of the motor and thereby permits more efficient operation at the lower speeds, as has been shown previously. This control combines

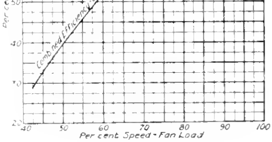


Fig. 13. Comparative Efficiency of BTS Motors and Direct-current Motors with Field Control Fan Load

the rotor transformer, line switches, inverse time limit overload relays, and undervoltage protection all in one unit as illustrated by Fig. 14. With the smaller motors (5 to 40 h.p.) the brushes are shifted by the hand controller, but for larger motors a hand wheel is used as shown in Fig. 3

Remote Push Button Speed Control

For installations requiring push button start and stop and push button speed control the brushes are shifted by a pilot motor which is geared to the brush rigging. If the service does not necessitate using the Y-delta combination of motor connections the control arrangement is very simple, since the only electrical connection necessary between the brush mechanism and line contactor is an interlock to prevent starting until the brushes have been returned to a predetermined low speed position. To vary the speed it is necessary to hold down the fast or slow button until the desired speed is obtained. A detailed view of this brush shifting mechanism is shown in Fig. 15.

In order to provide for automatic operation of the Y-delta change and also compensate for the accompanying change in speed so that uniform speed variation will be obtained over the entire range merely by pressing the fast or slow button, a drum master switch is also geared to the pilot motor. This switch carries the control circuit for the pilot motor and line contactors.

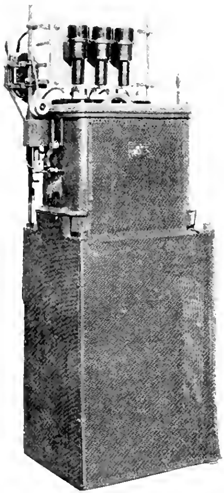


Fig. 14. Rotor Transformer for BTS 252-h.p., 650-r.p.m., 2200-volt Motor Equipped with Switch Overload Relays and Undervoltage Release

At a predetermined speed the motor connections are automatically changed from delta to Y, or vice versa, and the pilot motor immediately moves the brushes to a new position so as to bring the motor back to its former speed and eliminate a large break in the speed curve. In general appearance the control resembles Fig. 16, except that the rope wheel is omitted.

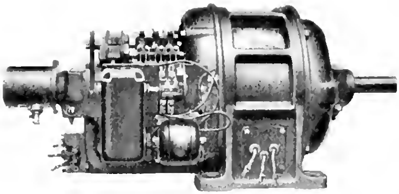


Fig. 15. Type BTS 10-h.p., 1200-r.p.m., 550-volt Motor, Showing Pilot Motor Control Mechanism

Pressure Regulator Control

For boiler draft fan operation, pump drives, etc., where it is desirable to automatically vary the speed in accordance with pressure or water level, equipment has been developed which provides automatic speed control from a pressure regulator or float, or manual control from push button stations in addition to push button start and stop. Automatic compensation for the Y-delta change is also included.

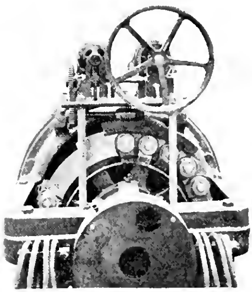


Fig. 16. Pilot Motor, Gear Train, Rope Wheel, and Drum Control Switches for Automatically Controlling a Brush-shifting Motor from Push Button Stations or Pressure Regulator

The complete control equipment necessary to provide these features consists of the following:

Primary control. Line and delta-Y contactor panels with necessary interlocks.

Secondary control. (Fig. 16.) Brush-shifting pilot motor, gear train, and drum control switches, arranged for pressure regulator control through the rope wheel, or for push button control. The BTS motor overload relays and pilot motor reversing contactors are mounted upon separate panel.

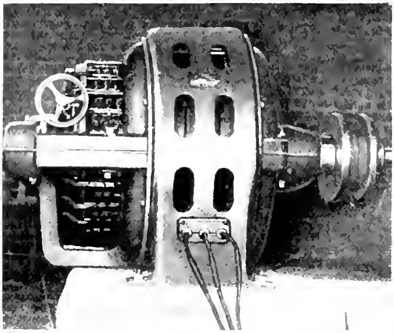


Fig. 17. BTS 100-h.p., 375-r.p.m., Three-phase, 440-volt Brush-shifting Motor Driving 100,000 Cu. Ft. Robinson Mine Fan at Aultman, Pa. This motor was installed in 1913

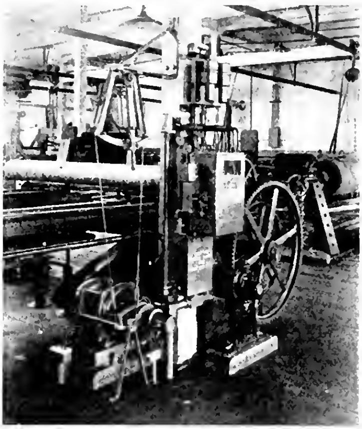


Fig. 18. BTS 7½-h.p., 1200-r.p.m., 220-volt Varying Speed Brush-shifting Motor (hand control) Connected by Chain to 50-ft. Woolen Tenter Frame. Hamilton Woolen Company, Southbridge, Mass.

If pressure regulator speed control only is desired the brush rigging may be driven by a rope or chain from a sheave mounted upon the motor control panel, the sheave in turn being driven by the pressure regulator through a rack and pinion. With this equipment the motor speed varies between predetermined limits in accordance with the pressure demand. If desired, provision may be made for automatically stopping the motor when the minimum speed is reached and automatically starting again when the pressure drops.

This arrangement is very simple but it does not allow push button speed control or automatically operated Y-delta contactors. Manual control is possible, however, at the regulator, since the pilot valve may be operated by hand.

Applications

In general these motors are applicable to any machine requiring speed variation at constant torque or less. For the majority of requirements a 2 or 3 to 1 speed range is ample; however, a greater speed reduction may be obtained if desired. It is always advisable to take advantage of the possibility of operating above synchronism, since for the same range the low speed efficiency and power factor is higher.

So far the majority of applications have been to textile mill machines, mine fans, ventilating fans, boiler draft fans, and pumps. (Figs. 17 to 23). There is no reason, however, why these motors should not be suitable for any variable speed drive where limited series characteristics are not objectionable.

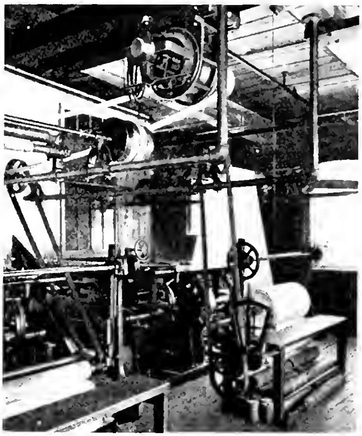


Fig. 19. BTS 10-h.p., 1200-r.p.m., 550-volt Brush Shifting Control, Varying Speed Motor Belted to Tenter Frame, Windsor Print Works, North Adams, Mass.

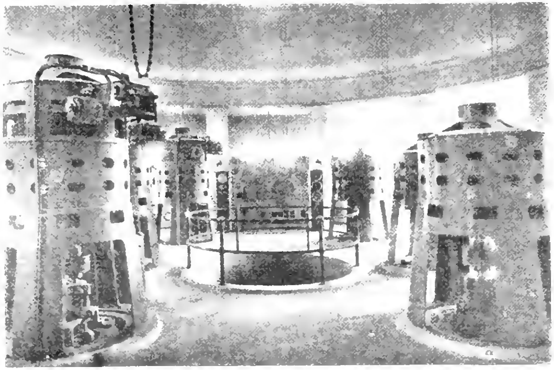


Fig. 20. Three BTS 150-h.p., 480-r.p.m., and Three 100-h.p., 400 r.p.m., 2200-volt Squirrel Cage Vertical Motors with Push Button and Float Switch Control Sewage Pumping Plant, Albany, N. Y

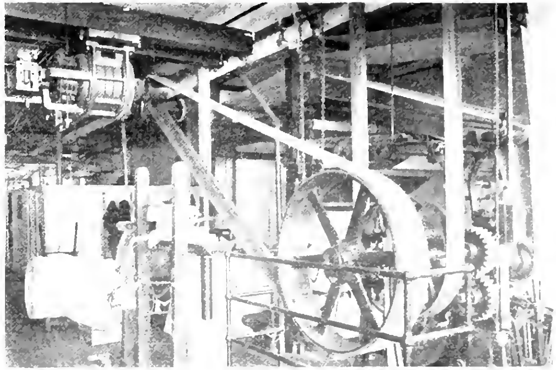


Fig. 21. BTS 25 h.p., 1200 r.p.m., 550-volt Brush-shifting Control Varying Speed Motor Belted to Cloth Printing Machine Windsor Print Works, North Adams, Mass. This motor was installed in 1914

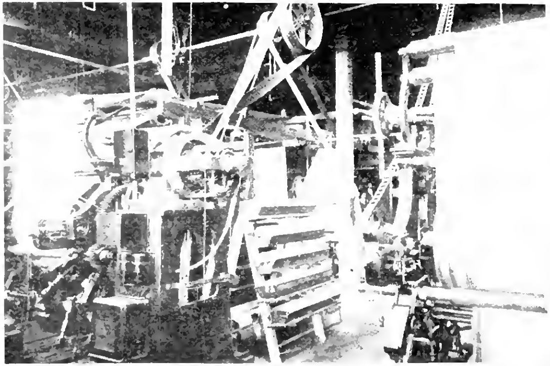


Fig. 22. BTS 25-h.p., 1200-r.p.m., 550-volt Varying Speed Brush-shifting Motor (semi-automatic control) Driving a Six-color Rice, Barton and Fales Cloth Printing Machine Imperial Printing and Finishing Co., Providence, R. I.

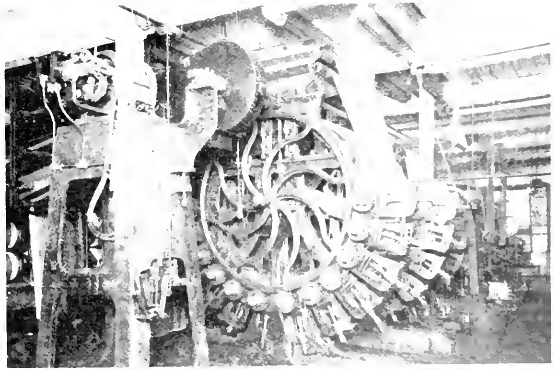


Fig. 23. BTS 40 h.p., 1200-r.p.m., 550-volt Motor (semi-automatic control) Twelve-color Rice, Barton & Fales Printing Frame and Motor Stand Chain Drive Greenville Finishing Co., Greenville, R. I.

SINGLE-PHASE ALTERNATING-CURRENT BRUSH-SHIFTING MOTOR

Theory of Operation *

The single-phase adjustable varying speed motor (type BSS) has operating characteristics similar to the polyphase machine, but is of

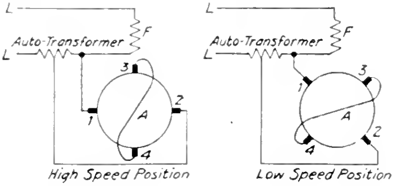


Fig. 24. Elementary Diagram of BSS Motor Connections

entirely different electrical construction. Instead of being a straight series motor capable of developing full load torque above synchronous speed, it is a series compensated repulsion motor as shown by the diagram of Fig. 24. The stator consists of the usual single-phase distributed winding while the rotor resembles a direct-current armature. Two sets of brushes bear on the commutator, one known as the energy brushes, which are short circuited, and the other as the compensating brushes, which are connected in series with the line through a series transformer. Usually the series transformer is built as an auto-transformer. The appearance of the motor is shown in Figs. 25 and 26.

Fig. 27 represents a two-pole motor with the brushes set for synchronous speed operation. The series brushes 5 and 7 are always 90 electrical deg. from brushes 3 and 4 and provide a field which is perpendicular to the axis of the rotor winding short circuited by brushes 3 and 4. With the brush position shown the current induced in the short circuited rotor winding by the stator field flux is a miximum and the torque developed by the motor is due primarily to the repulsion between this current and the field produced by the current flowing through the series brushes 5 and 7. This is the maximum torque and synchronous speed position.

By shifting the brushes through angle A (Fig. 28) the induced current flowing through brushes 3 and 4 is reduced proportionately to $\cos A$. Consequently when A equals 90 deg. the current in this circuit is zero and the torque and speed are zero. It is evident therefore that shifting the brushes 90 electrical degrees will vary the speed from synchronism to zero.

* A detailed development of the theory of the Type BSS motor is given in January, 1917, GENERAL ELECTRIC REVIEW.

Speed and Torque

The speed and torque characteristics are similar to those of the alternating-current, three-phase wound rotor motor or the direct-current motor with armature control, i.e., the speed varies with the load, decreasing when the load increases and vice versa. In applications demanding varying speed care should be taken to "motor" closely, i.e., the horsepower rating of the motor should compare as nearly as possible with the power required by the driven machine at normal speed. For example, if a 5-h.p. motor is applied to a machine having a demand of only three horsepower the excessive brush shift necessary for one-half speed operation will result in less stable speed-torque characteristics.

Shifting the brushes will cause little speed variation under no load. However, whenever an induction motor with secondary resistance control has satisfactory speed-torque characteristics the brush-shifting motor will have

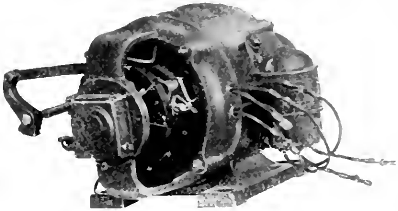


Fig. 25. BSS ½-h.p., 1800/900-r.p.m., 110/220-volt 60-cycle Motor

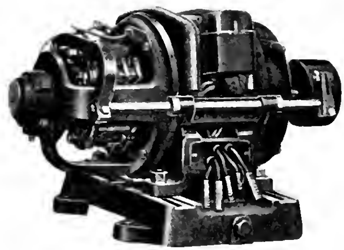


Fig. 26. BSS 2-h.p., 1800/900-r.p.m., 110/220-volt, 60-cycle Motor Showing Standard Assembly of Rock Shaft on Right Side Facing Commutator End

equally suitable characteristics (Refer to Fig. 29.) Since the BSS motor has series characteristics its no-load speed is high, but due to the saturation of the transformer the no-load speed is limited to about 50 or 60 per cent above synchronous speed.

The standard motor is designed to operate against full load torque with a speed variation of 2 to 1. Greater speed range can be obtained by specially designed windings, and in some cases a larger frame, as the heating and commutation at the low speeds is the limiting factor. With fan and similar loads, where the torque drops off rapidly with decrease in speed, the necessary reduction is secured by a wider shift of the brushes than when the load is heavy.

especially desirable since the rate of acceleration is dependent upon the rate of brush shift, and therefore is entirely under the control of the operator.

Efficiency and Power Factor

The efficiency and power factor curves, as given by Fig. 31, include 50 per cent speed reduction for both 100 per cent and 50 per cent torque. It should be noted that at 100 per cent speed and load the motor will operate

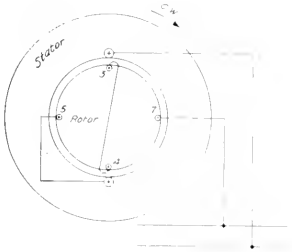


Fig. 27. Elementary Diagram of Two-pole Motor with Brushes Set for Synchronous Speed Operation

Fig. 28. Elementary Diagram of Two-pole Motor with Brushes Shifted Through Angle A for Reduced Speed Operation

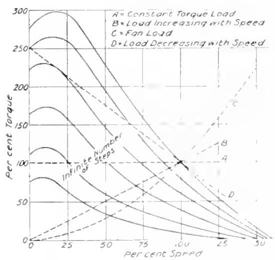


Fig. 29. Speed-torque Curves for a Single-phase Varying-speed, Brush-shifting Motor

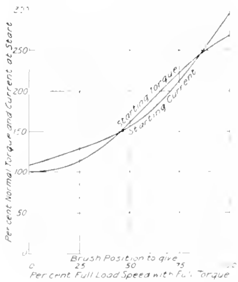


Fig. 30. Starting Curves for a Single-phase, Varying-speed Brush-shifting Motor

Starting Current and Torque

Fig. 30 gives the starting current and torque for different brush positions. When the brushes are set to give 25 per cent speed with full torque, the starting torque will be 115 per cent and the current approximately 130 per cent. These curves show that the motor may be started with the brushes in any position, but that preferably they should be in a low speed position in order to draw a minimum starting current from the line. The starting characteristics of these motors are

at unity power factor with an efficiency of 79 per cent, which is comparatively high for small alternating-current motors. At 50 per cent speed the efficiency decreases fifteen per cent and the power factor thirty per cent.

Rating

Standard BSS motors are built in capacities from $\frac{1}{4}$ to $7\frac{1}{2}$ h.p., 1800 and 1200 r.p.m., 110 and 220 volts, and are designed to develop full load torque over the entire range from full speed to one-half speed. All motors may be run in either direction, but only the sizes

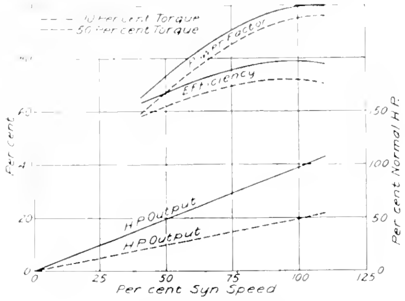


Fig. 31. Performance Curves for a Single-phase, Varying-speed Brush-shifting Motor

1 h.p. and larger are designed for reversing operation. If desired this type of single-phase motor can be built in capacities as large as 20 h.p., 1800 r.p.m.

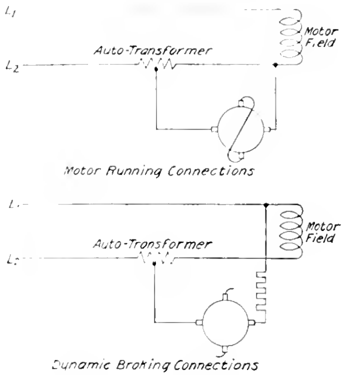


Fig. 33. Diagram of Connections of BSS Motor for Dynamic Braking

Control

Because of the variety of applications of this type of motor it is necessary to provide several different control arrangements. In general, the control consists of a double-pole line switch and some mechanical means of shifting the brushes. Fig. 32 illustrates some

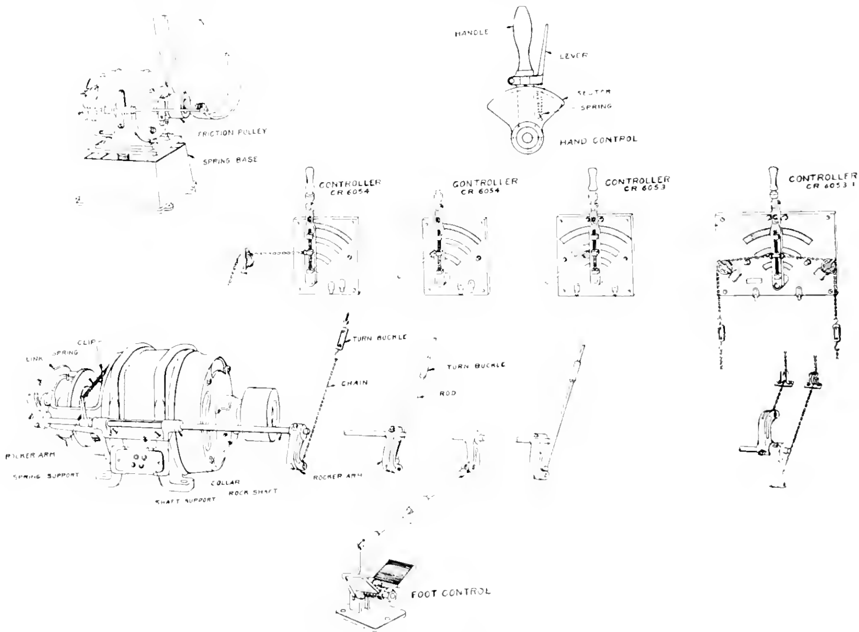


Fig. 32 Various Control Devices Used with BSS Motors

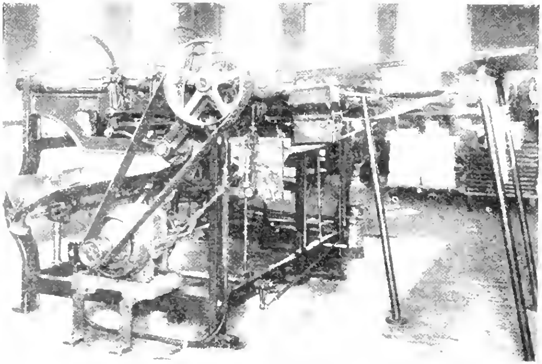


Fig. 34. Letter Folder Driven by Type BSS Motor with Foot Control

Fig. 35. Five BSS ½-h.p., 900/1900 r.p.m., Single-phase Varying-speed Motors, Operating Sutphen Machine Company's Finishing Lathes. Imperial Porcelain Works, Trenton, N. J.

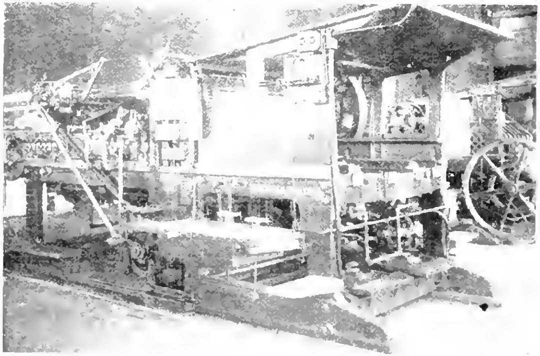


Fig. 36. Miehle Press Driven by Type BSS 3-h.p. Motor with Reversible Push-button Control. Speed controller mounted just below the feed board. Starting and stopping buttons are directly above the controller

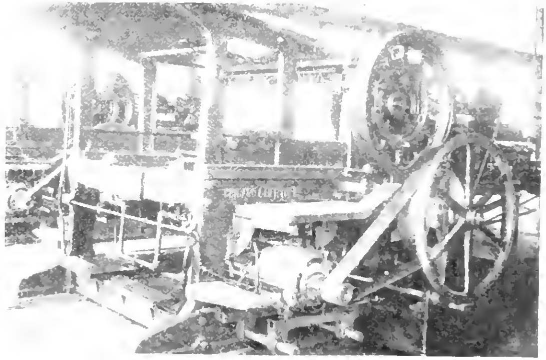


Fig. 37. Other Side of Press of Fig. 36, Showing Motor Mounted Within the Press Frame on special Brackets. The motor brush rigging is connected with the speed controller by a system of rods

of the various control equipments used. The devices are provided with connecting rods or steel chains brought over guide pulleys for connecting the motor brush yoke to the handle, thus making it possible to mount the controller at a considerable distance from the motor. If control at the motor is sufficient, a handle and sector may be used, and the motor started and stopped by a double-pole line switch or push button operated contactor.

The foot control used for printing press and similar drive also requires a double-pole line switch or contactor.

The dial control with rod or chain for reversing and for non-reversing duty provides for both starting and speed regulating.

The cut in the upper left corner (Fig. 32) illustrates a special arrangement in which the motor is mounted on a spring base for friction drive.

Reversible Operation

Reversing the type BSS motor is accomplished simply by shifting the brushes past the false neutral or zero speed point. The speed then builds up in the opposite direction as the brushes are shifted further. Non-reversible motors have a removable stop pin, and the direction of rotation is changed by setting the brush yoke to shift on the opposite side of this pin. Reversible motors have the pin removed, and the controller carries the brush yoke across neutral. This controller is arranged to break the electric circuit as the brushes pass through neutral.

Dynamic Braking

If required the control may be arranged to provide dynamic braking. The connections for this operation are given in Fig. 33.

Applications

Because of its simple control, high efficiency and power factor, and infinite number of speeds, these small motors have a wide field of application and have already thoroughly demonstrated their superiority to any other type of single-phase alternating-current motor for variable speed service. As the motor will deliver constant torque the horsepower output varies directly with the speed, rated horsepower being developed at rated full load speed. When the motor is operating against constant torque of normal to 75 per cent normal value 50 per cent reduction in speed may be obtained by shifting the brush yoke. Because of the limited series characteristics inherent in this type of motor, the speed will vary as the torque varies at any one setting of the brush mechanism. Therefore in applications where it is expected that the load will vary careful investigation must be made before recommending this motor.

The most common applications of these motors are to printing presses, textile mill drives, fans, pumps, and other miscellaneous machines in manufacturing processes. (Figs. 34 to 38.)

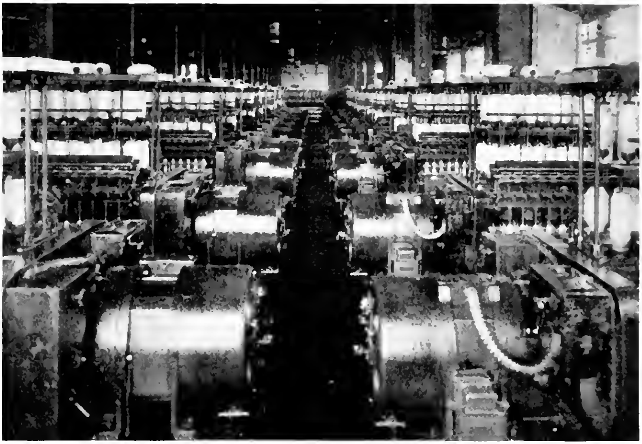


Fig. 38. Single-phase Varying Speed Spinning Frame Motors. Group showing coupling connected with P-10 non-automatic starters. Saratoga Victory Mfg. Co., Victory Mills, N. Y.

Water Japan Installations

By Wheeler P. Davey and P. Dunning
Research Laboratory — Compensator Department, Sprague Works
General Electric Company

In the August, 1919, issue of this magazine there appeared an article describing a colloidal solution of japan-base in water (known as "water-japan") and also the methods of applying it on a commercial scale. Since that time two departments of the Schenectady Works of the General Electric Company have continuously used this type of japan, and large conveyor ovens have been built and put in operation at the Sprague Works. In all three cases the hot-dip method is used exclusively. It is the purpose of the present article to describe these installations and to give the performance of the japan in them.—Editor.

Installations at the Schenectady Works, G. E. Co.

The oldest factory installation of water-japan equipment is still in use in the Switchboard Department. The basket-dip process is employed. The installation consists of an old electrically heated core oven which serves as a preheater, an iron japan tank, and a vertical revolving electrically heated baking oven (Fig. 1). The preheating oven is provided with drawers so that part of the load can be taken out without cooling off the remainder of the load. Each drawer holds six wire baskets, each capable of holding from 100 to 150 lb. of metal. These baskets are handled by a chain-falls suspended from an overhead track which runs from the loading station past the preheater and the japan tank to the baking oven and the unloading station. The japan tank is water-cooled by means of a coil extending all the way around the inside of the tank. At one end of the tank an iron partition runs from near the bottom to within two inches of the surface of the water-japan. In the bottom of the tank, behind this partition, is a series of air jets which aid in cooling the japan. A scrubber in the air-line removes any possible condensate which might have been carried along in the pipe. This scrubber consists of a vertical piece of four-inch pipe about ten feet long which contains about 18 inches of water at the bottom. The air bubbles through the water, past a baffle, and out through the top of the scrubber. The water in the scrubber is changed daily. A small centrifugal pump brings the cold water-japan from behind the partition into the main body of the tank. This pump is operated only while metal is being dipped. The cooling coil and one of the air jets are run continuously.*

The next oldest installation is in the Industrial Control Department. It differs from the one just described in that the ovens are both small box-type ovens. The baskets are smaller, holding from 20 to 40 lb., and are handled without the use of chain-falls. A galvanized iron tank of the "kitchen hot-water tank" type serves as an air scrubber. As in the case of the Switchboard Department, the work is of such a nature that it may be handled readily in baskets. It may be noted that small castings in this department are first water-japanned, and later machined as required.

*In building the japan tank, pump, cooling coil, etc., it is absolutely necessary to make sure that no material but iron or steel is used. If any copper, brass, bronze, galvanized iron, etc., is used, it will form a small electric battery in the presence of the water-japan and cause the japan-base to electroplate out of the solution.

Installation at the Sprague Works

The installation at the Sprague Works is the first to use water-japan on a large scale. It consists of three electrically heated conveyor ovens. Two of these have a maximum capacity of two tons per charge; the third has a maximum capacity of three tons per charge. Due to the lack of available floor space they are of the vertical, intermittent type. The dip-tanks are in a pit below the floor level. They differ from those in use in the Schenectady Works in that the cooling coil is placed behind the partition, and the air jets are placed on the end farthest from the partition. In this way the combined convection currents due to the air bubbles and the cooling coil cause a continuous circulation of japan past the cooling coils, thus keeping the temperature of the japan always below 70 deg. F. without the use of a pump. Each tank holds about 900 gal. of japan. This provides enough heat capacity in the japan itself to prevent undue temperature rise during dipping.

Large pieces such as compensator boxes and covers are hung individually from hooks on the bars of the conveyor. Small castings of irregular shape are dumped into baskets which are then hooked onto the bars. All metal which is japanned is more than 40 mils thick. After the oven is loaded, the doors are shut and the heat turned on. A thermostat at the top of each oven permits a maximum temperature of 500 deg. F. A mercury thermometer on the door shows the temperature at the coolest (bottom) part of

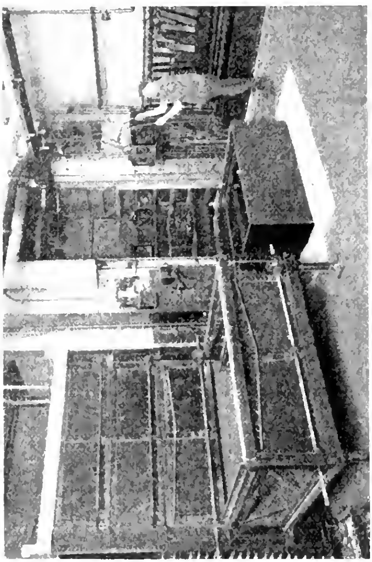


Fig. 1. Water-japan Installation in Switchboard Department, Schenectady Works, General Electric Company

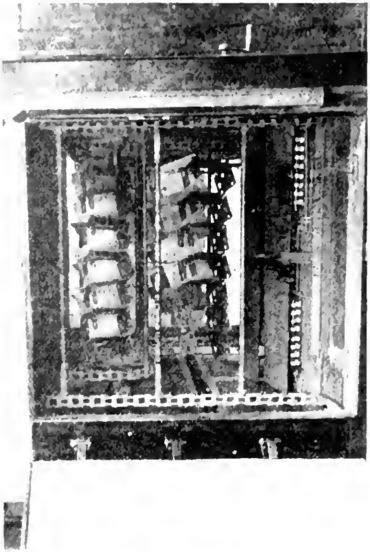


Fig. 2. Interior of One of the Water-japan Ovens at Sprague Works, General Electric Company

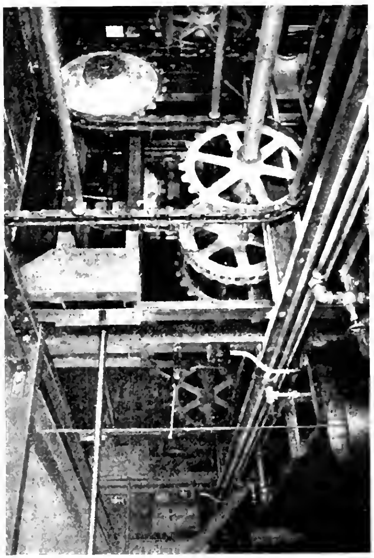


Fig. 3. Tanks and Bottom Portion of Conveyor of the Water-japan Ovens Shown in Fig. 2

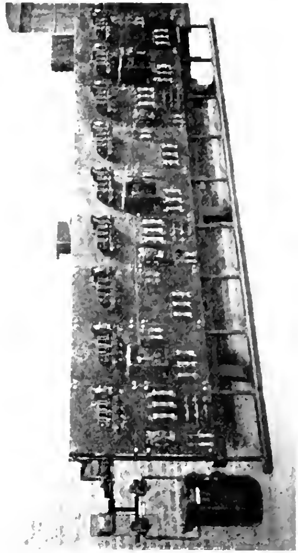


Fig. 4. Control Switchboard for Water-japan Ovens Shown in Fig. 2

the oven. It was originally intended to carry the preheat to 500 deg. F at all parts of the oven. This, however, did not prove practical due to the time required, and dipping is now started when the temperature at the bottom of the oven, just below the lowest loaded bar, reaches 400 deg. F. It is hoped that a slight alteration may later be made to remedy this defect so that the whole of the oven may be heated to 500 deg. F.

Dipping is done at a conveyor speed of not less than six inches per second. This speed is determined by the necessity for having every portion of each piece of metal at a temperature of 400 deg. F. or more at the instant it enters the japan. The speed of dip must therefore be at least as great as the rate of travel of the cooling wave along the metal. When the dipping operation is finished, the metal is back in its original place in the oven. The japan is baked for 20 to 30 min. The oven is then unloaded from one side and at the same time is reloaded from the other side.

The ovens were originally provided with fans in the ventilating ducts at the top in the same manner as is ordinarily done when ovens are built for use with inflammable japan. It has not been necessary to use these fans. The natural convection current past the fan blades and up the duct has been found to be quite sufficient to carry off the traces of water vapor and the products evolved from the japan-base itself during the baking process. It is found that the saving by not having to heat a strong current of air in the oven is practically enough to pay the cost of the preheating. Because of the great positive advantages inherent in preheating, manufacturers of japanning equipment recommend preheating ovens even when ordinary inflammable japans are used. These advantages are retained with water-japan by the hot-dip method, with the added advantage that the preheat costs practically nothing, since the cost of energy for preheating and baking with water-japan seems to be essentially the same as the cost for baking alone with ordinary japan. When operating on a load of 4000 lb., the efficiency of the two-ton ovens for preheating plus baking is 11 lb. per kw-hr. With smaller loads the efficiency is of course less. For instance, if the load is decreased to 1800 lb., the efficiency is only 6 lb. per kw-hr. The oven which has a capacity of three tons has never been loaded to its maximum, so that actual data are not available, but it is estimated that if it were so loaded its efficiency would be 11 lb. per kw-hr. These figures compare favorably with those obtained with box-type or other intermittent ovens using ordinary japan without preheat.

Action of the Japan

There has been no attempt to load these ovens with a homogeneous load; a single charge may contain castings large enough to be hung individually on hooks, small castings in baskets, and several sizes and shapes of punchings. The relative freedom from drip, which is a characteristic of water-japan, prevents material on one bar from being marred by japan dropping from the next higher bar,* and also prevents prohibitive scarring of the work which is dipped in baskets. This same property promotes cleanliness about the oven, as is shown by the photograph in Fig. 2, which was taken after the oven had been in operation for several weeks.

Due to the action of the preheat in cleaning the metal from oil and grease, the coat of water-japan is especially adherent. The weather-resisting properties have been tested by the engineers of another company (the report being therefore unbiased) who report that water-japan is as resistant to weather and abrasion as the best japan. Also, the finish is as good as is obtained with the best japan of the ordinary type under the same conditions. Data, taken on metal totalling several thousand square feet in area, show a coverage of a little more than 200 sq. ft. per gal. of water-japan.

Due to the low viscosity of water-japan, dirt drops readily to the bottom. Each hot particle of loose scale becomes coated with a thin layer of japan during the hot-dip, and at once begins to settle. The result is that, although water-japan may be cleaned in a centrifugal clarifier just like other japans if desired, for most purposes it may be considered as self-cleaning. It is advisable however that the tanks be emptied once a month and the japan-coated scale on the bottom removed with a shovel.

The japan seems to have wide time limits in baking between the temperatures of 400 and 500 deg. F., so that pieces baked at the bottom of the oven at 400 deg. F. are apparently as well baked as those which have been at the top of the oven (500 deg. F.) for the same length of time. As is the case with all other japans, the lower the temperature the

*Of course, the japan coat is not free from defects due to scale dropping from the conveyor system onto the work. This difficulty is inherent in the vertical type of conveyor oven.

longer the time required to bake, e.g., 300 deg. F. requires many times longer bake than does 400 deg. F.; however, the limits between the minimum time of baking at 400 deg. F. and the maximum at 500 deg. F. overlap to such an extent that if necessary the same baking time can be used for both.

In spite of the large amount of metal that is japanned daily by the ovens at the Sprague Works, it is not necessary to measure the concentration of the japan oftener than once a week. Since the solvent (water) is relatively non-volatile, there is no need for the daily addition of "thinner," so that the low initial cost of water-japan is further supplemented by the saving in the cost of thinner.

These advantages are nevertheless of but supplementary importance compared with the main purpose for which water-japan was developed—the absolute elimination of fire risk.

Heating Rotor Spiders by Induction

By Robert W. Wieseman

Alternating-current Engineering Department, General Electric Company

Large high-speed rotor spiders, which are usually shrunk on their shafts, are heated in an oven or by torches to expand the bore. The shaft may then be forced into place with ease and when the rotor has cooled the pressure at the fit is adequate. When the shaft has to be removed, however, the procedure is not so simple. Heating the rotor in an oven heats the shaft also, and local application of heat by torches is ineffective. The best way to expand the bore with respect to the shaft is to heat the spider electrically by induced currents, the steel spider acting as a short-circuited secondary. This article gives full information regarding this method of heating rotor spiders; the manner of winding the spider is described and illustrated, and formulas are given for determining the power, current, and voltage that will be required. The results of applications are shown by curves and instructions are included for the guidance of those who may have occasion to employ the method.—Editor.

Introduction

Rotor spiders are forced on their shafts either with a press fit or a shrink fit. Small slow speed rotor spiders have press fits while large high speed spiders usually have shrink fits.

The amount of shrink fit allowance required in the bore of a rotor spider depends upon the diameter of the bore and upon the stress at the overspeed to which the rotor may be subjected. Waterwheel driven alternators are designed to withstand overspeeds of 80 to 100 per cent while engine driven alternators, synchronous motors driving compressors, fans, pumps, etc., and motor-generator units usually have an overspeed of 50 per cent.

When a rotor spider is forced on its shaft with a shrink fit, the spider is heated in an oven or by torches to expand its bore. This enables the spider to be forced on the shaft with a moderate pressure and with little difficulty. The temperature T to which the spider should be heated to give an expansion b is given by the formula:

$$T = \frac{b}{0.000011\, d} + t$$

Where,

T = temperature of the spider in Centigrade degrees

t = room temperature in Centigrade degrees

d = diameter of the spider bore in inches

b = shrink fit allowance (expansion) in inches

A convenient rule to remember is that steel will expand one mil per inch length per 100 deg. C.

Difficulty is experienced, however, when the shaft is to be removed from the rotor because now the spider and shaft are one. If the spider and shaft are put into an oven and heated, the shaft will be heated as well as the spider, and consequently the shaft will expand the same amount as the spider, giving a net relative expansion of zero.

Torches can be played on the spider rim so as to impart most of the heat to the spider and as little heat as possible to the shaft. This is not satisfactory because the spider is heated only at spots, giving high temperatures at some parts of the spider and low temperatures at others. Large variations of temperature produce very high local stresses which may tend to crack the spider. Usually with this method heat cannot be imparted to the spider fast enough to heat it without heating the shaft. Thus the shaft becomes heated by conduction, and the net relative expansion again is practically zero.

Perhaps the best way to expand the spider bore, relative to the shaft, is to heat the spider electrically by using alternating current to induce a secondary current in the spider rim. This is accomplished by winding heavy bare copper cable circumferentially around the spider insulated with asbestos as shown by Fig. 1, and by sending an alternating current through this winding. The spider and cable winding constitute a short circuited transformer, the primary being the cable winding and the steel spider forming a one turn short circuited secondary.

Methods of Winding Primary

The primary winding can be wound on the spider in two ways: First, if a spider has arms or if it has holes parallel to the shaft, the primary can be wound around the rim as shown by Figs. 2 and 3. (Note in Fig. 3, the primary was wound in the dovetail slots.) Second, the primary can be wound circumferentially as shown by Fig. 1 and Fig. 5. The first method of winding the primary requires more time and labor and offers no advantages in heating; moreover, it is more difficult to calculate the impedance of the spider wound in this manner.

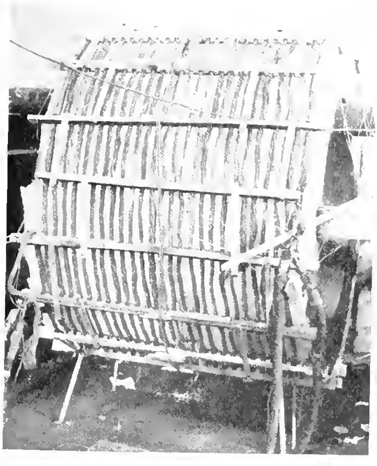


Fig. 1. Rotor Spider Wound to be Heated Electrically by Induction. Primary winding consists of 26 turns of 250,000 cir. mil bare copper cable wound circumferentially

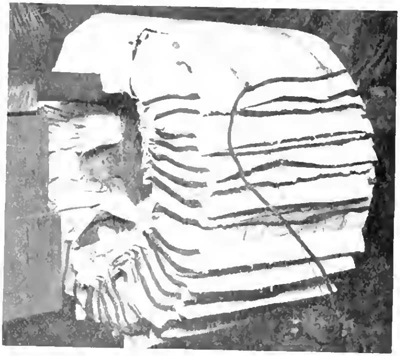


Fig. 2. Rotor Spider Wound to be Heated Electrically by Induction. Primary winding consists of 35 turns of 250,000 cir. mil bare copper cable wound around the rim through the ventilating holes in the web

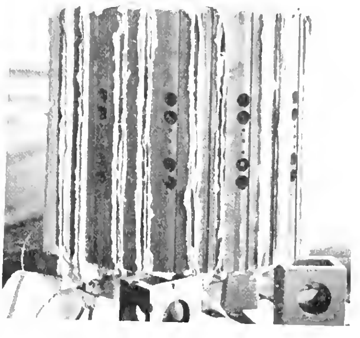


Fig. 3. Rotor Spider Wound to be Heated Electrically by Induction. The winding method employed is similar to that in Fig. 2 except the cable is laid in dovetail slots

Power, Current, and Voltage Required

The power input to the primary minus the RI^2 loss of the primary is the power input to the secondary which is absorbed by hysteresis loss and RI^2 loss. The hysteresis loss is very small in comparison with the RI^2 loss, and therefore it will be neglected.

The RI^2 loss raises the temperature of the spider. What then should be the rate of this temperature increase? Various tests show

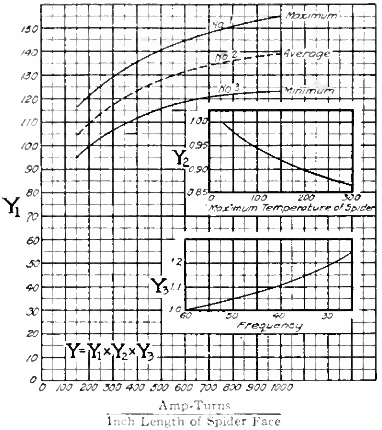


Fig. 4. Admittance Coefficient Y. Use Curve No. 1 when rotor spider has an irregular shape—large leakage flux. Use Curve No. 3 when rotor spider has no irregularities—small leakage flux

that a rate of average temperature increase of 100 deg. C. per hour is satisfactory, since in heating the spider at this rate little heat reaches the shaft. Obviously, the higher the rate of temperature increase of the spider the less the shaft will be heated; but this cannot be carried too far because the rim of the spider will attain a very high temperature and the hub temperature increase will be very small. This will cause unequal expansion and produce internal stresses in the spider which perhaps would result in its damage.

If there were no heat leakage and if the heat were uniformly distributed in the spider, then 6.25 watts would raise one pound of spider steel at the rate of 100 deg. C. per hour. Inasmuch as there is both heat leakage and uneven distribution of heat in the spider, a higher rate of energy must be dissipated. Tests show that about 15 watts per pound of spider should be used in heating a spider at the above temperature rate. Therefore,

$$P = 15\,W \qquad (1)$$

Where P is the power input to the primary winding in watts (RI^2 loss in primary neglected), and W is the weight of the spider in pounds.

For a given amount of power P the current will be

$$I = Y\frac{L}{N}\sqrt{\frac{P}{A}}\,* \qquad (2)$$

Where I is the current (amperes) flowing in the primary winding, Y is the admittance coefficient (see Fig. 4), L is the axial length of the spider in inches, N is the number of

* See appendix for derivation.

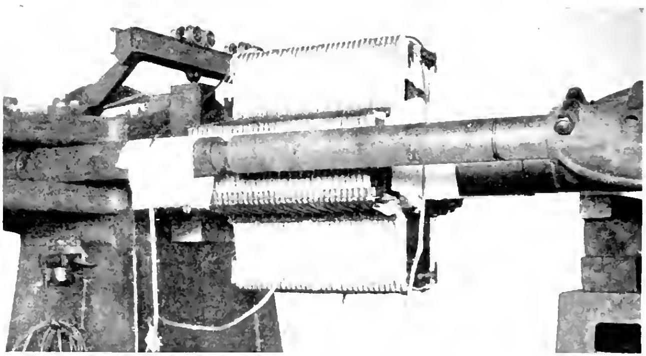


Fig. 5. Rotor Spider of a 4-pole, 7,000-kv-a., 750-r.p.m. Waterwheel Driven Alternator Wound to be Heated Electrically by Induction. Primary winding consists of 32 turns of 430,000 cir. mil bare copper cable

turns in the primary, and A is the area of spider surface covered by the primary.

Since $P = E\ I\ cos\ \theta$

$$\text{Therefore } E = \frac{N\sqrt{PA}}{YL\ cos\ \theta} \qquad (3)$$

Experiments show that the power-factor for steel spiders varies between 0.6 and 0.7. The power-factor for cast iron spiders would probably be about the same. If we take 0.65 as the average power-factor, it follows that

$$E = 1.5\frac{N}{YL}\sqrt{PA} \qquad (4)$$

Obviously the impedance will be:

$$Z = \frac{E}{I} = \frac{1.5\ N^2 A}{Y^2 L^2} \qquad (5)$$

The derivation of these formulas (see appendix) is based on the supposition that the primary is wound on the spider circumferentially and that the spider is a simple steel cylinder. The actual spider will have dovetail slots cut into it and will be more or less irregular in shape in comparison with a simple steel cylinder. The current paths in the spider, mutual induction, and depth of penetration are extremely complicated to calculate, and therefore the admittance coefficient Y must be determined by experiment. Fig. 4 shows how the values of Y for steel vary with current per unit length of spider, temperature, and frequency. It should be noted that the formulas apply only when the cable is wound uniformly on the spider circumferentially as shown in Fig. 1.

Fig. 4 gives the admittance coefficient Y as the product of the three factors; namely, Y_1, Y_2, and Y_3. It should be noted that the value of Y_1 varies between the limits of curves 1 and 3, 2 being the average. Y_1 also varies with the current per unit length of the spider, and therefore it must be obtained by trial. If the spider is quite irregular in its shape and construction, for example, the spider shown in Fig. 5, where it was impossible to wind the primary close to the spider, the maximum value of Y_1 (Curve 1) should be used. If the spider has no irregularities and approaches the shape of a simple cylinder, for example, the spider shown in Fig. 1, the minimum value of Y_1 should be used (Curve 3). A spider with a moderate degree of

Fig. 6. Rotor Spider of a 6-pole, 3530-kv-a., 500-r.p.m. Waterwheel Driven Alternator

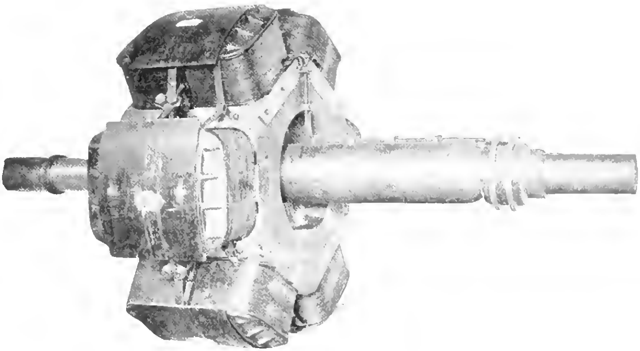


Fig. 7. Rotor of a 6-pole, 3530-kv-a., 500-r.p.m, Waterwheel Driven Alternator

irregularities and with large dovetail slots would have a value of Y somewhere between the maximum and minimum limits. Fig. 6 shows a rotor spider of this class and Fig. 7 shows this rotor complete. However, a rotor spider like the one shown in Fig. 5 is very unusual, and therefore it is safe to take the value of Y_1 between the region bounded by Curves 2 and 3 for ordinary spiders. The coefficient Y_2 corrects for temperature, and its value is unity for 25 deg. C. This coefficient is only used when the approximate current and voltage are required at the end of the heat run. Note that Y_2 varies as the maximum temperature of the spider face. Coefficient Y_3 corrects for frequency, and its value is unity at 60 cycles per second.

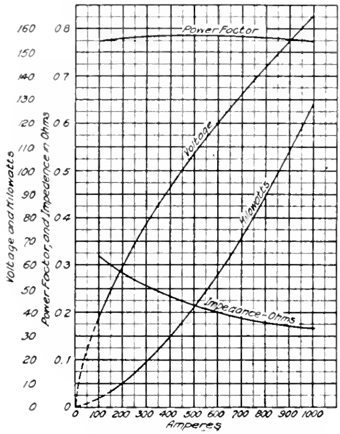


Fig. 8. Curves for Rotor Spider with Primary Wound Around Rim Through Holes in Spider

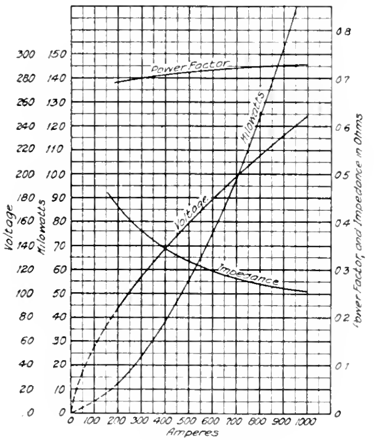


Fig. 9. Curves for Rotor Spider with Primary Wound Circumferentially

Impedance Tests

Fig. 8 shows the results of the impedance tests at 60 cycles per second on the spider of a 12-pole, 6000-kv-a., 500-r.p.m. waterwheel driven alternator (Fig. 2). The primary consisted of 35 turns of 250,000 cir. mil copper cable wound around the rim through the ventilating holes in the web.

Fig. 9 shows the results of impedance tests on the same spider at 60 cycles per second. The primary in this case consisted of 26 turns of 250,000 cir. mil copper cable wound *circumferentially* as shown by Fig. 1.

Fig. 10 shows the results of the impedance test at 60 cycles per second on the spider of a 4-pole, 7000-kv-a., 750-r.p.m. waterwheel driven alternator. The primary winding consisted of 32 turns of 430,000 cir. mil. copper cable (Fig. 5). Fig. 10 gives the values of effective resistance and reactance of the spider.

Fig. 11 shows the results of the impedance tests at 40 cycles per second taken on the spider mentioned above. Two impedance tests were taken, one when the spider was cold (temperature 35 deg. C. before heat

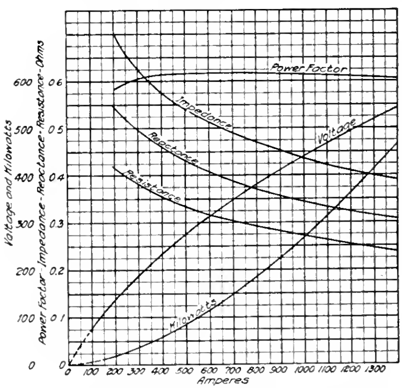


Fig. 10. Curves for Rotor Spider of a 4-pole, 7,000-kv-a., 750-r.p.m. Alternator, Frequency 60 Cycles. (See Fig. 5.)

run) and one when the spider was hot (average temperature 120 deg. C. after heat run). These tests show that the power-factor changes only a small amount with a change in temperature. The impedance increased 18 per cent when the maximum temperature of the spider rim increased 240 deg. C.

Heat Run

The spider of the 7000-kv-a. alternator mentioned above was heated electrically by induction while mounted in a hydraulic press which was used to force out the shaft after the spider bore had expanded sufficiently. The heat run was taken at a constant voltage of 380 volts and at a frequency of 40 cycles per second. Fig. 12 gives the results of the heat run. These curves show that the temperature rise of the spider surface was 220 deg. C. in 55 minutes. The temperature of the pole face was practically the same as that of the cable winding. Temperatures taken at various parts of the pole body indicate that most of the heat was confined to the pole surface. This shows that the currents induced in the spider penetrate the spider only a very small amount. The power-factor remained constant at 60 per cent during the entire run. The initial power was 303 kw. (14 watts per pound of spider) which in 55

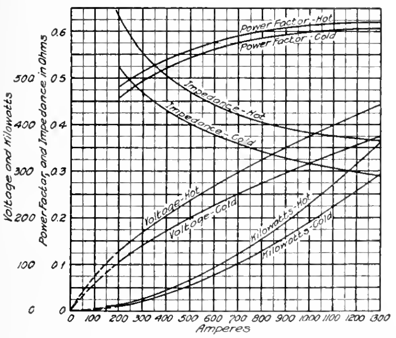


Fig. 11. Curves for Rotor Spider, Frequency 40 Cycles. Curves marked "cold" were taken before heat run. Average temperature 35 deg. C. Curves marked "hot" were taken after heat run. Average temperature 120 deg. C. (See Fig. 5.)

minutes decreased to 222 kw. or approximately 75 per cent of the initial power.

Power-factor

Tests on the same spider show that when the primary is wound around the rim, the power-factor (0.78) is a little higher than when it is wound circumferentially (0.7).

If the spider has an irregular shape, thus making it impossible to wind the primary close to the spider face at all points (which is

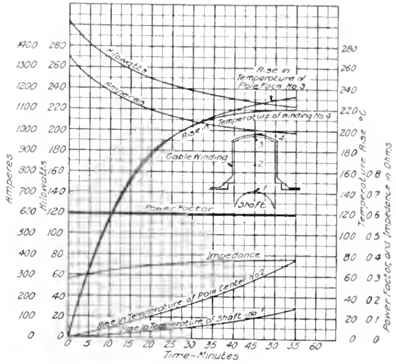


Fig. 12. Heat Run Curves, Frequency 40 Cycles, Constant Potential 380 Volts. Primary winding consisted of 32 turns of 430,000 cir. mil bare copper cable insulated with asbestos. (See Fig. 5.)

the condition for large leakage flux) as shown by Fig. 5, the power-factor will be approximately 0.6. If the spider has no irregularities, as shown by Fig. 1, the power-factor will be approximately 0.7.

The power-factor of a given spider is practically constant at commercial frequencies. Fig. 10 and Fig. 11 show that the power-factor for both 40 and 60 cycles per second is about the same within the current limits of 500 to 1200 amperes.

Frequency

With low frequencies the impedance of the winding will be so low that a very large current at low voltage will be required. This is undesirable because the necessary current capacity is not always available. It follows then that a frequency of 60 cycles per second is preferable.

Instructions

The following instructions should be observed when heating a rotor spider electrically by induction:

Pole Pieces. The pole piece and field winding must obviously be removed for two reasons: First, the primary winding could not be wound directly on the spider. It is very essential that the primary be wound as closely to the spider as possible. Second, the high temperature of the spider face would damage the field winding.

Insulation. The spider should be insulated with asbestos before the primary is wound on it. The asbestos insulation should not be too thick because, as previously stated, it is very essential that the primary be wound as close to the spider as possible.

Primary Winding. Wind only one layer of bare copper cable 250,000 cir. mil or larger on the spider and wind as many turns on as possible, covering the entire spider face. Brace the turns securely so that they cannot touch one another.

Heat Run. The values of power, current, and voltage can be easily calculated from equations 1, 2, and 3, respectively, using the values of the admittance coefficient Y as given by Fig. 4.

It has been found that if electrical energy be dissipated in a spider for an hour at the rate of 15 watts per pound of spider, its bore will expand sufficiently to enable the shaft to be removed with the application of only a moderate force. This follows from the rate of average temperature increase of 100 deg. C. per hour as previously stated. At the above temperature rate the maximum temperature of the spider, which occurs at the face, may reach a temperature as high at 300 deg. C.

The power input to the spider at the end of the heat run will be approximately 75 per cent of the initial value of power if the voltage is constant during the run. This is due to the increase of impedance with temperature. The value of power, given by equation 1, namely $P=15\ W$, is the initial value of the power.

Conclusion

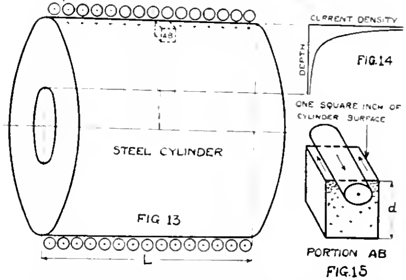
This method of heating rotor spiders for removing shafts with shrink fits has proved to be very satisfactory. Shafts have been removed from spiders of various shapes and constructions with no difficulty whatsoever. The average time consumed in preparing the spider for heating, namely, insulating it with asbestos, winding the primary, and wiring, is approximately one day. Spiders for high speed 60-cycle machines ranging from 5000 to 12000 kv-a. require approximately 35 kw. of electrical power per 1000 kv-a. to heat them.

APPENDIX

Derivation of Expression for Current and Voltage

It has been previously stated that when the primary is wound around the rim through the arms or holes in the spider, as shown by Fig. 2, it is very difficult to derive an expression for the impedance of the winding. However, if the primary is wound circumferentially, as shown by Fig. 13, an expression can be readily derived.

Consider the spider as a simple steel cylinder wound circumferentially with a uniform winding, assuming for convenience one turn per inch length of cylinder as shown by Fig. 13. Let an alternating current flow through this winding and at a certain instant assume that the current flowing through the primary winding in the direction as indicated. Then by Lenz's law, the current flowing in



Figs. 13, 14, and 15. Schematic Diagrams for Deriving Mathematical Expressions for Current and Voltage

the steel cylinder (which is a one turn short-circuited secondary) would be opposite in direction to the current flowing in the primary. If the mutual induction were perfect and the secondary resistance were zero, the current per inch length of the cylinder would also be equal to the current flowing in the primary. Let I be the current in amperes flowing through the primary winding, and let N be the number of turns in this winding. Then the current in amperes per inch axial length of the coil is $\delta_p=\frac{NI}{L}$, where L is the length of the cylinder in inches. The current in amperes per inch length induced in the cylinder (secondary) will be $\delta_s=K\frac{NI}{L}$, where K is a coefficient depending upon the mutual induction. The current induced in the cylinder flows near the surface of the cylinder (within a fraction of an inch) due to the well known screening effect of an alternating current in inductive magnetic materials. It follows that the current density in the cylinder is maximum on the surface and decreases rapidly as the depth increases. The approximate variation of current density with the depth is shown by Fig. 14.

Now consider the total RI^2 loss to be concentrated in the surface layer of the cylinder. The resistance of this layer will be an equivalent resistance, as far as loss is concerned of such a value which when multiplied by the square of the total current in the cylinder will give the total RI^2 loss in the cylinder. Let the depth d, in inches, of this surface layer be the depth of penetration.

Let AB, Fig. 15, be a portion of the cylinder whose height is equal to the depth of penetration d, whose upper base is one square inch of cylinder surface, and whose lateral edges are radial lines. The length of the current path in this portion is one inch, and the area of the current path is d square inches. Therefore, the resistance which the portion AB offers to the current flow is $\frac{\rho}{d}$ where ρ is the resistivity of steel in ohms per inch cube. The loss p, in watts, in this portion is $p=\frac{\rho}{d}\left(K\frac{NI}{L}\right)^2$. Let A be the area of the cylinder face, in square inches, over which the primary is closely and uniformly wound. Then the total loss in the cylinder is

$$P=\rho\frac{K^2}{d}\;A\frac{N^2I^2}{L^2}$$

or

$$I=\sqrt{\frac{d}{\rho K^2}}\;\frac{L}{N}\sqrt{\frac{P}{A}}$$

Let

$$\sqrt{\frac{d}{\rho K^2}}=Y\ \text{(admittance coefficient)}$$

Then

$$I=Y\frac{L}{N}\sqrt{\frac{P}{A}} \qquad (2)$$

Calculation of the Depth of Penetration

The admittance coefficient in equation (2) is $Y=\sqrt{\frac{d}{\rho K}}$, where d is the depth of penetration in inches, ρ is the resistivity of steel in ohms per inch cube, and K is a coefficient depending upon the mutual induction. The value of Y has been found by experiment, and since ρ is known, and the value of K can be assumed, it follows that the value of d can be approximated.

For example, take the 12-pole, 6000-kv-a., 500-r.p.m. spider, Fig. 1 and Fig. 8. At a primary current of 1000 amperes at 60 cycles per second $Y=119$.

$\rho=5.6\times10^{-6}$ Assume $K=0.7$

$Y=\sqrt{\frac{d}{\rho K^2}}$ $\therefore d=0.039$ inch

Values of depth of penetration obtained in this way on the same spider at various frequencies indicate that the depth of penetration varies inversely as the square root of the frequency and practically agree with the values given by Dr. C. P. Steinmetz in "Theory and Calculation of Transient Electric Phenomena and Calculations."

A Generator for Making Lightning

By J. L. R. Hayden and N. A. Lougee

General Engineering Laboratory, General Electric Company

The phenomena attending a lightning discharge has many factors such as voltage, [illegible], wave shape, etc., which have been the subject of much study by engineers. The apparatus we [illegible] this article bids fair to give more definite knowledge concerning these phenomena than we have been [illegible] obtain heretofore. Its probable value to the engineering world is very great.—Editor.

Dr. Steinmetz's camp on the Mohawk River, above Schenectady, was recently struck by lightning. There is a tree overhanging the camp; the lightning struck this tree, tearing the bark from the upper portion and then jumped to the camp, where it divided. One branch passed to ground through one of the 8 in. by 10 in. posts forming the front of the camp, tearing off large splinters. The other branch shattered a window and then jumped to the camp's local lighting circuit which is fed by a storage battery. In this local lighting circuit apparently a stationary high frequency oscillation was set up. This was shown by the destruction of some of the lamps connected into the circuit, while other lamps located between these were undamaged and so showed that there were low voltage nodes between high voltage crests. From this lighting circuit the lightning then discharged through a number of paths, shattering or tearing splinters from several of the 2 in. by 4 in. supporting posts of the camp, a screen door, a bed, etc. In the bedroom, the lightning jumped from a loose end of wire, connected to the lighting circuit, to a looking-glass and from there to ground. It shattered the glass into many pieces, and threw these across the room, some for a distance of over 20 feet. As far as possible these pieces were collected and fitted together. They showed a curious marking where the amalgam had been partly burned off by the lightning discharge.

Fig. 1. Lightning Generator; high-tension transformer on floor at left behind table, kenotrons above, glass plate condensers at the side, main regulating sphere gap (vertical) in front of condensers, racks of regulating resistance rods immediately beneath, and test gap on barrel below

Dr. Steinmetz reached the camp within twenty-four hours and took accurate records and photographs of the effects of the lightning discharge.

Such information is of considerable scientific interest. Its industrial applications in leading to better means of protecting buildings should be of great value, but the most significant use for any additional knowledge in this direction will be in enabling electrical engineers to devise better means of protecting electrical apparatus and electric circuits from lightning discharges. If a "lightning generator" could be built which would be capable of reproducing experimentally the observed effects of lightning it would have great value as a means of testing electrical apparatus and protective devices such as lightning arresters. It is obvious that we could place much more confidence in protective apparatus tested by such means than is at present possible where our methods of test are chiefly based on theoretical reasoning.

In order to study the phenomena of lightning and the high power high voltage transients of short duration which occur in electric circuits due to atmospheric discharges, or due to internal causes, it was necessary to construct a high voltage condenser of very large capacity capable of discharging instantaneously a very large amount of energy. Such a piece of apparatus could be used for testing protective apparatus under conditions equal to or even more severe than the conditions imposed by most thunderstorms.

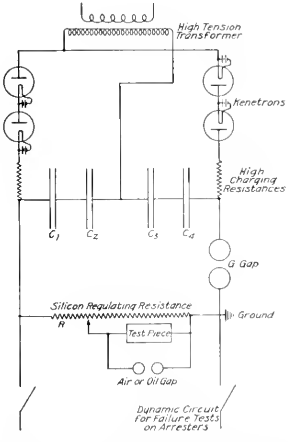


Fig. 2. Connection Diagram of the Lightning Generator as Set Up for Testing with or without the Addition of Dynamic Current

The apparatus that has been designed and built is shown in Fig. 1. Fig. 2 is a diagram of the connections. It consists essentially of a large capacity built up of glass plate condensers which are charged to a constant unidirectional voltage by a set of kenotrons which are energized by an alternating-current transformer. These kenotrons discharge over leads of negligible resistance and of the lowest possible inductance through a spark gap into the desired circuit to be tested.

Two hundred glass plate condensers are arranged in two racks of two rows each to enable them to be conveniently connected either all in multiple, or with two groups in series with 100 in multiple, or with four groups in series and 50 in multiple, thus making various voltages available for testing purposes.

In Fig. 1 the transformer and kenotrons will be seen in the foreground, and the two banks of condensers at the side of them. The main regulating sphere gap, *G*, will be noticed in front of the condensers, while just below this gap are the racks of resistance *R*. Just under this resistance and connected across it is the air gap used for measuring the voltage of the impulse. It will be seen that the discharge circuit is made as short as possible in order to have the inductance a minimum.

The capacity per plate is 0.008 mf. and a single plate stands about 30 kv. before it begins to flash over at the edge. The total capacity, with all the plates in multiple, is therefore 1.6 mf., and at 30 kv. per condenser plate, gives the stored energy:

$$W = \frac{1}{2}Ce^2$$
$$= \frac{1}{2}\times 1.6\times 10^{-6}\times 30^2\times 10^6$$
$$= 720 \text{ Joules.}$$

The minimum inductance of the leads connecting the apparatus is estimated at 0.016 mh. With the condenser plates connected 4 in series, 50 in multiple, giving 0.1 mf. capacity, we obtain a surge impedance of the discharge circuit of:

$$z_0 = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.016\times 10^{-3}}{0.1\times 10^6}} = 12.6 \text{ ohms}$$

This gives a maximum discharge of 9,500 amperes at 120,000 volts corresponding to a momentary maximum of over a million kv-a. at a discharge frequency of:

$$f = \frac{1}{2\pi\sqrt{LC}} = 126{,}000 \text{ cycles}$$

or, in a damped circuit, $(r = z_0)$, we may get a single impulse, rising to 120,000 volts, 4700 amperes, or a quarter million kilowatts, in 2.3 microseconds, and vanishing again with the same rapidity, also ($r = 400$ ohms), an impulse rising to 120,000 volts in one-fifth microseconds, and maintaining, within 10 per cent of this voltage for 5 microseconds, at 300 amperes discharge current.

A most difficult problem was to find a resistance for controlling the amount, character, rate and duration of the discharge. Such a resistance must be practically non-inductive, and must be capable of absorbing a large amount of energy at a very high rate, without appreciable change. High resistance wire resistors were excluded because of their inductance. The various graphite or carborundum clay mixtures were unsuitable, on account of their negative voltage and current characteristics. A reasonably satisfactory resistance was finally found in cast silicon rods. A cast silicon rod 10 in. long and 0.22 in. diameter, measured about 6 to 8 ohms each. The terminal connection is made by thin sheet iron caps, which are shrunk over the ends at red heat, the steel and silicon welding together at this temperature. While such silicon rods are rather fragile mechanically, and have to be handled carefully, they have proven to be relatively the most satisfactory. Their resistance decreases with an increase of temperature, that is, they have a negative temperature coefficient; but the resistance does not change permanently even if they become red hot, provided that the terminal connections do not change.

The arrangement shown in Fig. 2 permits testing apparatus against suddenly applied impulse voltages of any desired duration, steepness and voltage. These may occur during a thunder storm whenever a lightning flash in the clouds equalizes the electric stresses in the cloud, and thereby sets free the bound electrostatic charge of the line which was held by the charge of the thunder cloud, and thereby suddenly impresses a high voltage on the line. Assuming, as estimated by Dr. Steinmetz, 20,000,000 volts as the average potential changes in the thunder cloud, the voltage produced on the line by the setting free of its bound charge is as large a part of the cloud voltage as the height of the line is of the height of the cloud. With an estimated height of the lower surface of the thunder cloud as 1000 meters, and 6 meters as the height of line, the line charge would be:

$$\frac{6}{1000} \times 20 \times 10^6 = 120 \text{ kv.}$$

At this voltage the lightning generator gives a capacity about equal to that of 8000 feet of primary distribution circuit.

Usually four condenser sections in series are used as shown in Fig. 2 by C_1, C_2, C_3, C_4, to permit using 120 kv. as was estimated to be about correct. The condenser C is shunted through a sphere gap G which fixes the condenser voltage at the moment of discharge, and by a non-inductive resistance R, consisting of a number of frames of silicon rods. By tapping across various parts of the resistance R, different fractional voltages of constant duration and wave shape are derived, and by varying the resistance R, the duration of the voltage is changed. By measuring these fractional voltages of known duration, by various types of gaps, in air and in oil, information on the time lag of the discharge of these gaps is derived.

As an illustration of the use of this lightning generator in testing lightning arresters, may be mentioned that it has already been the means of obtaining valuable information in regard to the marked effect that the static spark-over of the arrester has on the dynamic following the static. Often lightning arresters have been tested by connecting them into a circuit of suitable voltage and sufficient power, and then sending a static spark through the lightning arrester, and, if the dynamic charge does not follow the static, or is opened at the end of the first half wave, the arrester has been considered satisfactory. Tests with the lightning generator, however, show that the dynamic current and voltage which a lightning arrester can open, depends to a considerable extent on the energy of the static discharge which precedes the dynamic. With the full power discharge, combinations of spark gaps and shunting resistances may fail to open the dynamic current following the discharge, although the same combinations opened it safely with a static impulse of less energy and equal dynamic power at even higher voltage. This may account for the failure of some types of arresters in service which had appeared satisfactory in laboratory test.

Genelite: An Improved Bearing Alloy

By E. G. Gilson

Research Laboratory, General Electric Company

The ideal bearing metal would be one which would operate dry with results comparable with those that are now obtained by proper lubrication. Such a highly desirable bearing material seems impossible of realization and the next best thing is a bearing metal which will not seize nor score when bearing surfaces are permitted to run dry through negligence or accident. Genelite, a new synthetic bronze-graphite bearing material, developed by the Research Laboratory of the General Electric Company, possesses this quality as has been shown by numerous tests. A short description of the composition of Genelite and its characteristics are given in this article. Editor.

All machinery may be classed as a composite of rigid members moving about pivots or bearings. As the industrial world has progressed and developed, the importance of its bearings to any given machine has become more and more emphasized.

These bearings have now become of such importance that it is perhaps safe to say that a large proportion of all machinery is designed around them; and it is usually at the bearings that trouble first develops. A few years ago this relative importance was not so great, and users in general were educated to the belief that bearing troubles were something that could not be helped—therefore must be endured.

However, the greatly increased strength of modern steel alloys created a desire for greater output from a given size machine, and the resulting increase in load and speed between rubbing surfaces intensified bearing troubles and focused attention on the need for better bearings.

In general there were two methods of attacking the problem, viz.: first, to improve the bearing itself either by design or through the development and use of better bearing metals, or both; second, to improve the lubrication of the bearings either by the use of a better lubricant or a better method of applying it, or both.

The new bearing metal Genelite is a distinct advance by the first method.

This material is a synthetic bronze of high grade, having uniformly distributed throughout its mass approximately 40 per cent by volume of very finely divided graphite. It is made by thoroughly mixing the finely powdered oxides of the metals composing the bronze with sufficient graphite to completely reduce them and leave in excess of this amount the graphite content desired in the finished material. This reduction process must be carried on at temperatures below the melting point, and therefore the material cannot be cast, as are ordinary bronzes. It is shaped by molding under high pressure while still in powdered form. As the powder does not flow readily under pressure it is necessary to use a complicated mold, and confine this operation to only the simplest shapes.

Although the finished material has the appearance of bronze, it cannot be machined easily by ordinary methods, as it rapidly dulls the cutting tool. It does grind very easily, however, and this has been found to

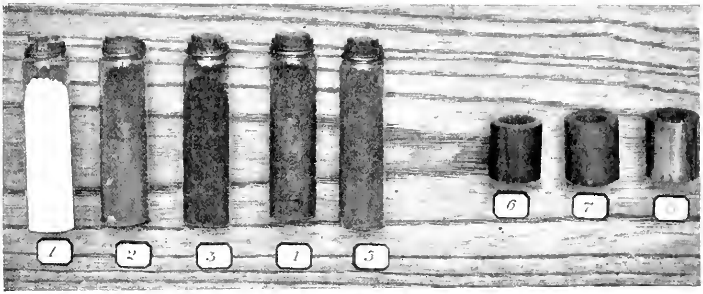


Fig. 1. Some of the Stages in Manufacturing Genelite

Nos. *1*, *2*, and *3*, Raw Materials; *4*, Graphite; *5*, Mixture Ready for Pressing; *6*, Bushing Pressed from the Powder; *7*, Bushing after Final Bake; *8*, Finished Piece be the most satisfactory way to perform the machining operations.

Genelite has not the physical characteristics of ordinary bronze. It is absolutely "dead" when struck; it has comparatively

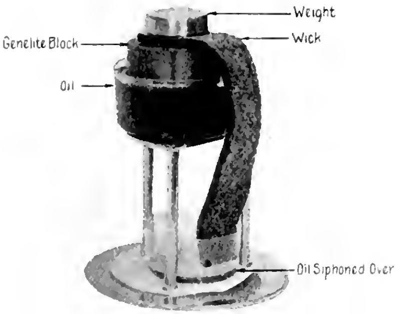


Fig. 2. Test Demonstrating Porosity of Genelite

low tensile strength and elongation, and the ultimate strength and yield point are practically identical at 8000 lb. per sq. in. Under compression, however, it will withstand 50,000 lb. per sq. in.

by thinking of a metallic sponge having graphite particles firmly held or clamped within its pores. In this connection it should be remembered that the graphite is so securely held that it cannot escape except by disintegration of the whole mass.

The porosity is such that the material will absorb from 2 to 3 per cent by weight of oil. This feature is well illustrated in Fig. 2, which shows oil being siphoned from the upper to the lower vessel by capillarity through the Genelite block to the wick, and by the wick to the lower vessel. This peculiarity is taken advantage of in some practical applications, as will be mentioned later.

A very marked advantage that Genelite has is that a bearing never seizes, as this term is commonly understood. That is, the shaft and bearing material never weld or flow together, with the consequent disastrous results. This self-lubricating property makes it extremely difficult to damage a Genelite bearing, even though the oil supply is stopped for a considerable length of time. This property makes it possible to operate Genelite with a minimum supply of oil, and it is taken advantage of in many applications, such as in tilting motors, where the standard oil ring practice cannot be used, because the oil will run out of the bearings when tilted. In this case, by providing an oil-tight space or

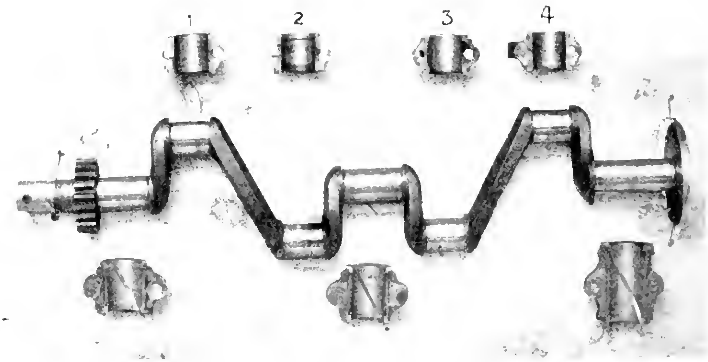


Fig. 3. Crank Pins and Main Bearings of an Automobile After 20,000 Miles Service. Connecting Rod Bearings Equipped with Genelite. The main bearings showed decided wear, while the crank pins were barely polished and the connecting rod bearings had not come to a full seat

These characteristics are explained by the structure of Genelite, which is not like that of the metals or alloys, but is of a porous nature. The best conception of it is perhaps obtained

receptacle in the housing on the outside of the bushing, and means whereby the oil is kept in contact with the bushing, capillarity will carry sufficient oil to the bearing surface.

Another application of this same sort is on high speed spindles. In such places too much oil is a detriment, and the method outlined above works extremely well. In one place it was found that by using Genelite in this manner the hardened steel shaft that was formerly used could be replaced by a soft steel shaft, the oil consumption reduced over one-half, and the care of cleaning and truing the bearings reduced to nil. This freedom from wear of both bearing and journal in this and many other tests under actual service conditions demonstrates one of the most marked advantages of this new material.

Genelite may be used as a self-lubricating bearing in places where such use is a necessity. But applications of this sort should not be compared with properly lubricated bearings; compared with other self-lubricating materials it gives exceptional results.

Owing to its spongy structure it is advantageous to give Genelite a greater allowance for press fits than is customary with other materials; also it need not be held to such close limits. In most applications a greater clearance on running fits is beneficial, and this increased clearance is not productive of noise.

Calculation of Synchronizing Power

By E. S. Henningsen

Alternating-current Engineering Department, General Electric Company

In introducing this article the author calls attention to the fact that, in order to avoid ambiguity, the use of the term "synchronizing power" must be accompanied by a statement of the conditions concerned because as yet there is no universally accepted definition of the term. He also points out that confusion is almost certain to result from the neglect in any particular case to determine carefully just which of the several powers exchanged is the synchronizing power. Assuming two generators running in parallel through a tie line and pulled apart by a fixed angle, he analyzes the operation under three generator conditions: constant bus potential; constant virtual voltage (constant magnetic flux); and constant nominal voltage (constant field excitation). For each of these he deduces thoroughly useful formulas for synchronizing power and later discusses their application in practice.—Editor.

The term "synchronizing power" is used rather indiscriminately by engineers to mean either the power P that is exchanged between alternators operating in parallel (when pulled apart by an angle θ) or $\frac{dP}{d\theta}$, the rate of change of that power per degree change in the angle. The result is considerable confusion unless the term is accompanied by a definition. Without attempting to argue which of these points of view is the better, it would seem that the term "synchronizing power" should apply only to the power exchanged and that $\frac{dP}{d\theta}$ should be given another name. Since the latter is more of the nature of a coefficient, it might for instance be called "synchronizing coefficient" or "synchronizing power coefficient." The question of definition is one that should be settled by the A. I. E. E. Standardizing Committee.

There is also some confusion regarding just what power exchange is the synchronizing power. For instance, suppose two alternators in parallel through a tie line are pulled apart by an angle θ. There is then a power* output P_1 of the machine which is ahead in phase, the power input P_2 to the machine which is behind in phase, P_3 the power lost in the tie line, and P_4 the average of P_1 and P_2. Which one, or what combination, of these is the synchronizing power? To draw an analogy we might consider P_1, P_2, and P_3 are links in the chain that holds the two generators in synchronism, and our principal interest in the problem is the determination of the strength of the weakest link, that is, the maximum power at the point where the two generators or systems break out of synchronism.

For example, suppose a single generator is operating in parallel with a large bus and the generator drops behind in phase due to its prime mover slowing down. Obviously, the power lost in the line between the bus and the generator is not part of the power that tends to accelerate the generator and so keep it in step. Hence the weakest link in the chain is P_2, the power received at the generator terminals. Assume now that the prime mover speeds up and the generator takes a position ahead in phase. It is equally evident that P_1 is now the power that acts against the accelerating force of the prime mover tending to keep the generator from pulling out of step. Hence P_1 or P_2 may be considered as the synchronizing power depending on whether the generator is assumed to be speeded up (ahead in phase), or slowed down (behind in phase).

The average* of P_1 and P_2 or P_4 is often used in calculations of power exchange

*"Stability of High-power Generating Stations," by Dr. C. P. Steinmetz, Proc. A.I.E.E., June, 1920.

although it has no real meaning. It becomes very useful in investigating the conditions after the machines have broken out of synchronism and are slipping by each other because symmetrical equations may be thus obtained which greatly simplify the calculations. The error involved in using the average power is, of course, proportional to the resistance.

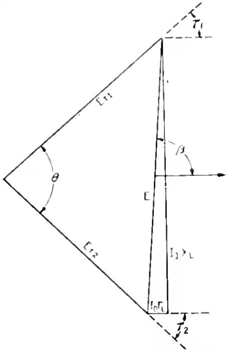


Fig. 1. Vector Diagram of Two Alternators with Constant Bus Potential, Paralleled Over a Transmission Line and Pulled Apart by the Angle Θ

No attempt has been made in this article to consider conditions other than those of steady strain, the equations derived applying only up to the break-out point and assume steady conditions for each value of displacement angle.

In the derivation of the equations for P_1, P_2, P_3, and P_4, three general operating conditions have been assumed: First, constant bus potential; second, constant magnetic flux in the generators; and third, constant field excitation. The equations for these different conditions are all of the same form, the only difference being the values of voltage and impedance that are used in each case.

Fig. 1 shows the vector diagram assuming two generators with constant bus potential paralleled through a transmission line and pulled apart by an angle Θ.

E_{T1} = terminal voltage of generator No. 1, assumed to be ahead in phase.

E_{T2} = terminal voltage of generator No. 2, assumed to be behind in phase

E = resultant of E_{T1} and E_{T2}

Θ = displacement angle between generators

I_0 = current flowing as a result of voltage E

r_L = resistance of the line between generators

X_L = reactance of the line between generators

$Z = r_L + jX_L$

$\cos\beta$ = power-factor of circuit of impedance Z

τ_1 = angle between E_{T1} and I_0

τ_2 = angle between E_{T2} and I_0

$K = \text{ratio}\ \dfrac{E_{T2}}{E_{T1}}$

The synchronizing power tending to hold in step generator No. 1 which is ahead in phase is:

$$P_1 = E_{T_1} I_0 \cos\tau_1 = \frac{E_{T1}^2}{Z}\left[\cos\beta - K\cos(\Theta+\beta)\right] \quad (1)$$

The synchronizing power tending to hold in step generator No. 2 which is behind in phase is:

$$P_2 = E_{T2} I_0 \cos\tau_2 = \frac{E_{T2}^2}{Z}\left[\frac{1}{K}\cos(\Theta-\beta) - \cos\beta\right] \quad (2)$$

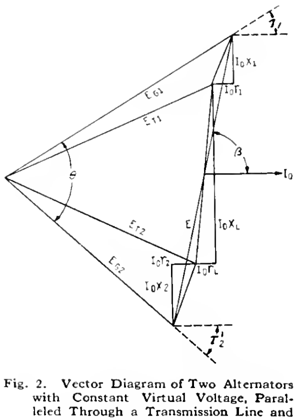


Fig. 2. Vector Diagram of Two Alternators with Constant Virtual Voltage, Paralleled Through a Transmission Line and Pulled Apart by an Angle Θ

The power lost in the tie line between the generators is:

$$P_3 = P_1 - P_2 = \frac{E_{T1}^2}{Z}\left[\cos\beta\,(1 - 2K\cos\Theta + K^2)\right] \quad (3)$$

The average power is:

$$P_4 = \frac{1}{2}(P_1+P_2) = \frac{E_{T1}^2}{2Z}$$

$$[2\,K \sin\Theta \sin\beta + \cos\beta\,(1-K^2)] \quad (4)$$

The maximum value of P_1 occurs when $\Theta = 180-\beta$ and is:

$$\text{Maximum } P_1 = \frac{E_{T1}^2}{Z}[\cos\beta + K] \quad (5)$$

The maximum value of P_2 occurs when $\Theta = \beta$ and is:

$$\text{Maximum } P_2 = \frac{E_{T2}^2}{Z}\left[\frac{1}{K} - \cos\beta\right] \quad (6)$$

The maximum value of P_3 occurs when $\Theta = 180$ and is:

$$\text{Maximum } P_3 = \frac{E_{T1}^2}{Z}\cos\beta\,(1+2K+K^2) \quad (7)$$

$$\text{Maximum } P_4 = \frac{E_{T1}^2}{2Z}$$

$$[2K \sin\beta + \cos\beta\,(1-K^2)] \quad (8)$$

The second assumed condition of operation, that of constant virtual voltage, i.e., constant magnetic flux in the generators is represented by the vector diagram, Fig. 2.

E_{G1} = virtual voltage corresponding to the magnetic flux of generator No. 1, assumed to be ahead in phase

E_{G2} = virtual voltage corresponding to the magnetic flux of generator No. 2, assumed to be behind in phase

E = resultant of E_{G1} and E_{G2}

r_1 = resistance of generator No. 1

r_2 = resistance of generator No. 2

X_1 = leakage reactance of generator No. 1

X_2 = leakage reactance of generator No. 2

$Z_1 = r_1+r_2+r_L+j(X_1+X_2+X_L)$

Other quantities are as in Fig. 1.

The equations for the condition of constant magnetic flux are:

$$P_1 = \frac{E_{G1}^2}{Z_1}\left[\cos\beta - K\cos(\Theta+\beta)\right] \quad (9)$$

$$P_2 = \frac{E_{G2}^2}{Z_1}\left[\frac{1}{K}\cos(\Theta-\beta) - \cos\beta\right] \quad (10)$$

$$P_3 = \frac{E_{G1}^2}{Z}\left[\cos\beta(1-2\,K\cos\Theta+K^2)\right] \quad (11)$$

$$P_4 = \frac{E_{G1}^2}{2Z}\left[2\,K\sin\Theta\sin\beta + \cos\beta\,(1-K^2)\right] \quad (12)$$

Fig. 3 shows the vector diagram assuming the third condition of operation, that of constant nominal voltage, i.e., constant field excitation on the generators.

e_{01} = nominal voltage [illegible], a fictitious electromotive force which is proportional to the field current. The curve of nominal electromotive force is a straight line passing through zero and the normal voltage point on the saturation curve)

e_{02} = nominal voltage of generator No. 2, behind in phase

X_{s1} = effective reactance of armature reaction of No. 1 generator

X_{s2} = effective reactance of armature reaction of No. 2 generator

$Z_2 = r_1+r_2+r_L+j(X_1+X_{s1}+X_L+X_2+X_{s2})$

Other quantities are as in Fig. 2.

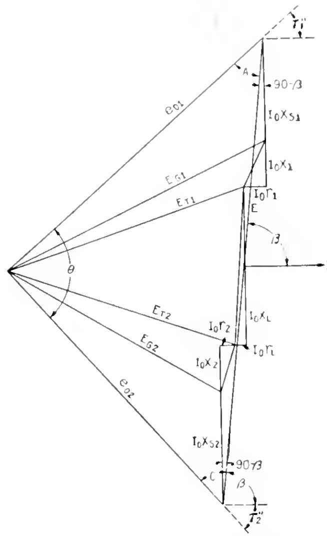


Fig. 3. Vector Diagram of Two Alternators with Constant Nominal Voltage, Paralleled Over a Transmission Line and Pulled Apart by an Angle Θ

The equations for this case are:

$$P_1 = \frac{e_{01}^2}{Z_2}\left[\cos\beta - K\cos(\Theta-\beta)\right] \quad (13)$$

$$P_2 = \frac{e_{02}^2}{Z_2}\left[\frac{1}{K}\cos(\Theta-\beta) - \cos\beta\right] \quad (14)$$

$$P_3 = \frac{e_{01}^2}{Z_2}\left[\cos\beta\,(1-2\,K\cos\Theta+K^2\right] \quad (15)$$

$$P_4 = \frac{e_{01}^2}{2Z_2}\left[2K\sin\Theta\sin\beta + \cos\beta(1-K^2)\right] \quad (16)$$

It will be seen that under any of the three assumptions the equations have the same form, the only difference being the voltage and impedance to be used. The voltage in any case is of course that voltage which is assumed to be constant as the machines are pulled apart, and the impedance is that over which the resultant of the constant voltages acts. If the terminal voltage is used, the impedance is only that of the line. If the virtual

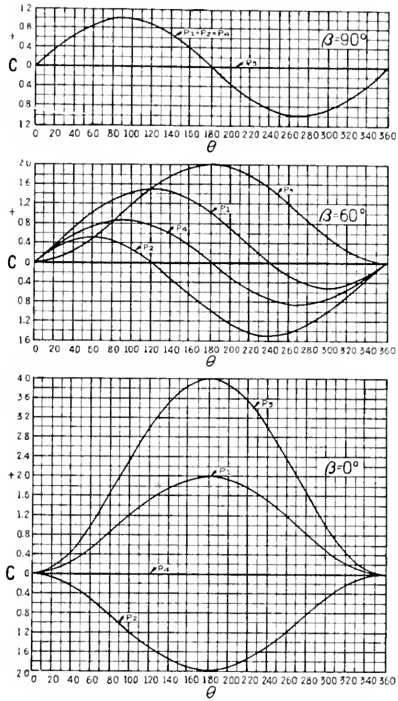


Fig. 4. Curves Showing Variation in P_1, P_2, P_3 and P_4 with the Angle θ for Power-factor Equal to Cos β, 0, 0.5 and 1.0

voltage is used, the impedance must include the leakage reactance of the generators as well as that of the line; and if the nominal voltage is used, the effective reactance of armature reaction is included in addition to the generator leakage reactance and the line impedance.

In the application of these formulas to practical cases, there can of course be no question as to when to use constant field excitation. The condition of constant bus potential obtains when the generator capacities are large and the impedance of the tie line high enough so that with automatic voltage regulators the voltage can be held up as the load transfer over the line is increased. If the swings of load are very rapid the condition approaches that of sudden short circuit, that is, the flux in the generator remains practically constant, but the terminal voltage and field current both vary. It might also be assumed that there would be cases where the capacity of the generator was not large enough in proportion to the tie line to keep the voltage up, and where the automatic voltage regulator would put on the field excitation at such a rate as to maintain approximately constant flux.

Under these three operating conditions, therefore, the variation in the amount of synchronizing power that is obtained is very great and is illustrated in Fig. 5, which

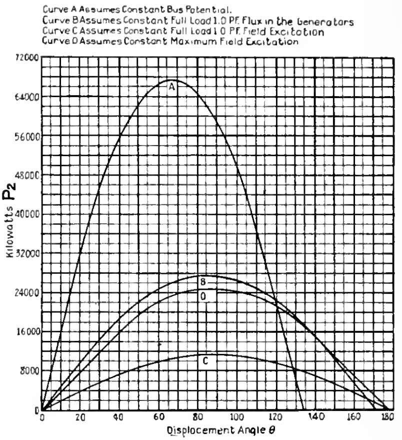


Fig. 5. Calculated Synchronizing Power of Two 12,000-kv-a. 6600-volt Generators Paralleled Through a Transmission Line

gives the calculated values of synchronizing power against dropping out of step due to the slowing down of one generator for an installation consisting of two 12,000-kv-a. generators. If the generators are hand controlled and the field setting is that of Curve C, then if the machines are suddenly pulled apart by an angle θ and held there, the synchronizing power would start out as Curve B and gradually, as the flux could change to adjust itself to a steady condition, would reduce to Curve C at a rate depending upon the time constant of the generator. With voltage regulators instead of hand control, the power received is represented by Curve D. Obviously, in this case, constant bus potential could not be maintained to the limit of synchronizing power.

Fig. 4 shows the variation in P_1, P_2, P_3, and P_4 when $K=1$ for three different impedance angles: $\beta=90$; $\beta=60$; and $\beta=0$. The coefficient C is the bracket term of equations (13), (14), (15) and (16). When considering the curve of P_1, positive values of C represent power delivered and negative values of C represent power received. For the curve of P_2, positive values of C represent power received, negative values of C, power delivered. When $\cos\beta=0$, P_1 and P_2 are equal since there is no loss in the line. When $\cos\beta=1$ (which of course can only occur on the assumption of constant terminal potential), an inspection of the equation for P_2 will show that if $K=1$ there can be no power delivered to generator No. 2, hence if the circuit contains resistance but no reactance, there can be no synchronizing power (See also Fig. 6). However, if K is less than

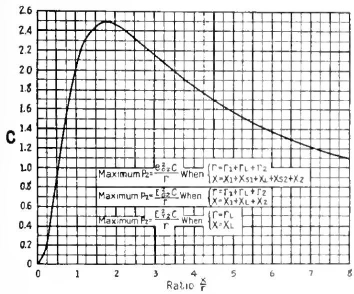


Fig. 6. Curve Showing Variation in Maximum P_2 for Constant Values of Resistance and Varying Values of Reactance When $K=1$

one, that is, if the voltage of the lagging machine is less than that of the leading machine, then the synchronizing power is no longer zero.

In this connection it might be noted on the assumption of two alternators paralleled over a line containing only resistance, that with constant and equal terminal voltages the synchronizing power would be zero; while with equal field excitation, since the reactance of the machines comes into the equation, the synchronizing power may be a considerable quantity. But with equal terminal voltages, the field excitation or nominal electromotive forces are not constant; the line current being in phase with the re-

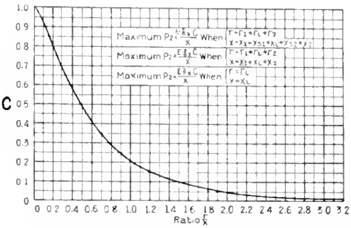


Fig. 7. Curve Showing Variation in Maximum P_2 for Constant Values of Reactance and Varying Values of Resistance When $K=1$

sultant of the terminal voltages demagnetizes the lagging and magnetizes the leading generator. The result is that the ratio of nominal electromotive forces is such that the synchronizing power is also zero when calculated on this basis. If on the other hand, the nominal electromotive forces are maintained equal and constant and the line contains only resistance, the terminal potentials do not remain constant, but that of the lagging generator becomes less than that of the leading generator. Hence K is less than unity and the synchronizing power will be the same whether the nominal or terminal electromotive forces are used in the calculation.

Investigating P_2 for maximum conditions it will be found that for a given value of Z, P_2 is a maximum when $r=0$; for a given value of X, P_2 is a maximum when $r=0$; and for a given value of r, which is the usual condition in practice, P_2 is a maximum when $X=r\sqrt{4K^2-1}$. If the voltages of the two machines are equal, P_2 is a maximum for a given value of r when $X=\sqrt{3}\,r$. Fig. 6 shows the variation in maximum synchronizing power P_2 when $K=1$, for different ratios of X/r, assuming a constant value of r; and Fig. 7 shows the variation when a constant value of X is assumed.

The maximum power P_3 lost in the line occurs for a given value of Z when $X=0$;

and for a given value of X when $X=r$. The maximum value of the average power P_4 occurs for a given value of Z when $r=0$; and for a given value of r when $X=r$. The maximum value of the power delivered P_1 (when $K=1$) occurs for a given value of Z when $X=0$; for a given value of X when

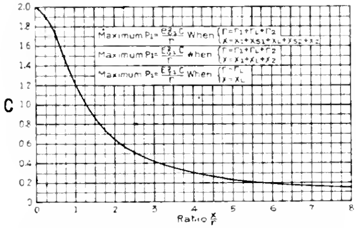


Fig. 8. Curve Showing Variation in Maximum P_1 for Constant Values of Resistance and Varying Values of Reactance When $K=1$

$r=X/\sqrt{3}$; and for a given value of r when $X=0$. Figs. 8 and Fig. 9 show respectively the variation in maximum P_1 (when $K=1$) for constant r and varying X and constant X and varying r.

Conclusions

The term "synchronizing power" should be used to mean the power exchange; and $\frac{dP}{d\theta}$, the rate of change of that power, should be given another name. Also it is necessary to specify whether synchronizing power against speeding up or slowing down is meant, since these two values are different by the loss in the line between the machines. Since for power-factors less than unity the power received by the generator which is behind in phase (P_2) is less than the power delivered when the machine tends to speed up or advance in phase (P_1), it would seem that in practical calculations P_2 should be considered the synchronizing power. The equations developed in this article are all for single-phase values of voltage and impedance (line to neutral); and for three-phase operation, the calculated power should of course be multiplied by three. In applying them to a practical case, the operating conditions must be investigated to determine what particular electromotive force may be assumed to be constant. The impedance to be used is the total impedance across which is impressed the resultant of the assumed constant voltages of generators No. 1 and No. 2. The synchronizing power will be a maximum for a given value of resistance when the reactance of the chosen circuit equals $\sqrt{4K^2-1}$ times the resistance.

It is difficult to say just what value of synchronizing power is necessary for satisfactory parallel operation since so many variable factors, due to operating conditions, enter into the problem. E. C. Stone, in the August, 1919, A. I. E. E. Proceedings recommends a synchronizing power equal to the kilowatt capacity of the smaller plant to be paralleled where the load fluctuations are a relatively small percentage of their capacity, and one and one-half times the kilowatt capacity of the smaller plant where the load fluctuations are relatively large. This seems to be a safe figure since cases of successful operation can be found where the calculated synchronizing power is considerably less. It is hoped that tests will be made and reported on in the future which will give

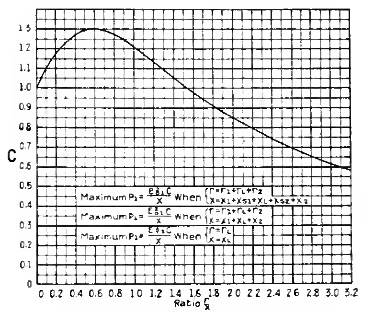


Fig. 8. Curve Showing Variation in Maximum P_1 for Constant Values of Reactance and Varying Values of Resistance When $K=1$

more data on the operation of alternators when paralleled through various amounts of resistance and reactance and the amount of synchronizing power necessary for stable operation.

Accounting for Steam Consumption*

By A. R. Smith

Construction Engineering Department, General Electric Company

Mr. Smith advocates the conduct of a steam generating plant according to the principles that are observed in the conduct of all other well managed businesses, that is, to keep a strict accounting of all steam that is generated and consumed. It is only by comparison of these quantities that leaks and inefficiencies may be detected and the most economical operation effected. The problem is simply one of metering the boiler feed water and the delivered steam and tabulating these amounts in such form as to permit of a ready interpretation of performance. Mr Smith recommends the form for this balance sheet and enumerates the items that should be entered in the several columns.—Editor.

It is highly essential to the proper conduct of any business, whether it be the production, sale or distribution of a commodity, that a statement be prepared at set intervals for the purpose of striking a balance between debit and credit accounts. Any well managed industry will, at least once a year, account for the quantity of articles disposed of and inventoried against the quantity produced. In many instances the difficulty of obtaining such data on commodities, because of the time required for production and the wide distribution of parts throughout a factory, precludes the possibility of showing a balance for shorter than yearly periods. On the other hand, if the time required to complete the manufacture of the commodity is relatively short, valuable records can readily be maintained to show the detail costs, the waste, and the possible improvements in operating facilities or methods of production.

The operation of a steam electric power plant or a steam heating plant is not essentially different from that of other manufacturing plants. It produces steam or electric power, or both. While these products, the production of which is completed in minutes instead of days or months, may appear less tangible than ordinary commodities, they can readily be measured. In this case production is immediately followed by consumption and there is, therefore, no stock pile from which to inventory at intervals. This short period of production and disposition naturally makes improvements in operating methods more conducive to economies than when the commodity requires a longer time to manufacture and consume.

Steam Power Plant Products

The products of a steam electric power plant are steam and electricity. Often only a portion of the steam produced by the boilers is converted into electric energy, the remainder being utilized for heating and other industrial purposes. The only practical method by which to record performances for such a plant is to meter each product and to consider the boiler room as the steam producer and the turbine room the power

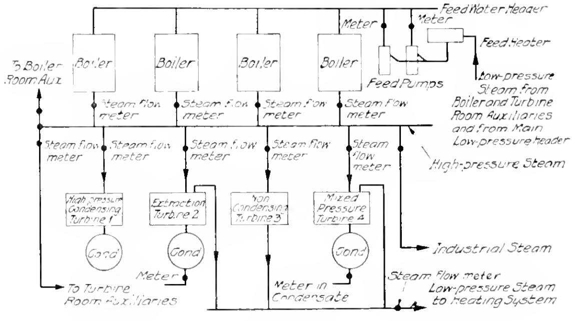


Fig. 1 Diagram Illustrating the Location of Flow Meters to Obtain Data for Balance Sheets

* Published simultaneously with *Power*.

producer. The turbine room as well as the heating system then purchases a certain amount of steam from the boiler room. This method of analysis is equally essential to the plant whose steam is all converted into electric energy, since in any instance the economy of steam production should be carefully checked. Such a record cannot so easily be maintained when the production costs are all charged directly to electric power without regard to the quantity of steam generated or consumed.

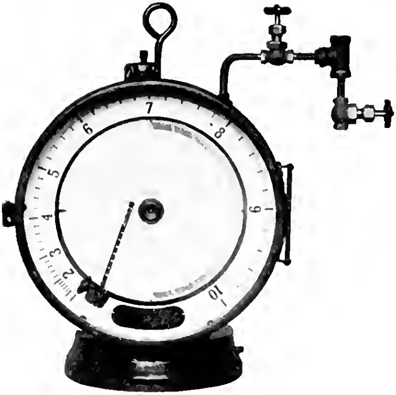


Fig. 2. General Electric Indicating Recording Flow Meter

In the commercial introduction of electricity, electric energy has been measured in every conceivable manner and no concern would consider its production or distribution without a thorough accounting: in fact, meter records are kept which show the energy consumption on the smallest feeder circuits.

On the other hand, the metering of steam, water and air has heretofore been neglected largely because satisfactory meters for the purpose have not been available until the last few years.

Units of Measurement

All commodities, tangible and intangible, are susceptible of measurement, although in some cases a concise inventory or accounting is rather expensive to obtain. Most commodities are measured or counted by units which are readily understood because of common-place and long continued usage. The accepted units of measurement for heat and power are as definite and simple as the common units used in everyday practice. The chief difference is that the units of measurement for heat and power cannot be visualized and therefore are often discredited by those not familiar with engineering terms. The unit of measurement for electric energy, the kilowatt-hour, was for many years generally regarded as the least tangible and understandable, but the extensive use of electric light and power in the home has now made it quite generally understood.

Pound or thousand-pounds generally used for the measurement of steam should be no more difficult to visualize as a unit than pounds of water, since steam is nothing more than water in the form of vapor.

Units Commonly Used in Power Plant Practice

Kilowatt: Unit for measuring electric power: that is, the rate of production or consumption of electrical energy.

Kilowatt-hour: Unit of electric energy or work. The product of power and time (in hours). Kilowatt-hours = kilowatts × hours.

Pounds of water per hour: Unit of water demand. Employed in measuring the rate at which water is fed to boilers.

Pounds of steam per hour: Unit of steam demand. This unit shows the rate at which steam is produced or consumed. This unit of weight does not represent a true value of power, because the actual heat required to produce a pound of steam varies with the pressure, superheat and sensible heat in the water. It may be advantageously used,

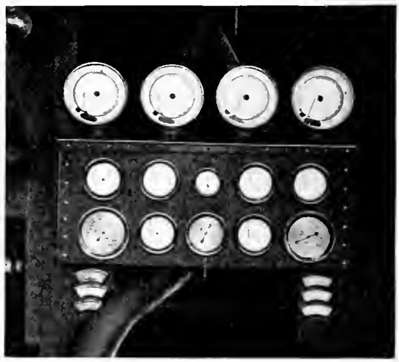


Fig. 3. General Electric Steam Flow Meters Installed in a Large Central Station

however, for small plants because it simplifies calculations but for larger plants the heat consumption should be expressed as equivalent pounds of steam from and at 212 deg. F.

Note:—For convenience in accounting and preparing balance sheets, the units Pound of Water, Pounds of Water per Hour, Pound of Steam and Pounds of Steam per Hour are often expressed in "thousands," thereby eliminating the use of such large numbers.

B.t.u.: Unit of heat commonly used in this country. The quantity of heat required to raise one pound of water 1 deg. F. at or near 39.1 deg. F., the maximum density of water.

Equivalent pounds of steam from and at 212 deg. F.: Unit used for the reduction of steam measurements to a common basis. It represents the weight of water that could be evaporated from the temperature of 212 deg. F., into dry and saturated steam at 212 deg. F. by the actual amount of heat transferred to the feed water in the boiler. It is equal to the total heat in the steam under boiler conditions, minus the heat in the feed water, divided by 970.4, the latent heat of steam at 14.7 lb. absolute. For example, 1 pound of steam at 250 lb. pressure and 250 deg. of superheat, produced from feed water at 150 deg. F., is equivalent to 1.257 lb. of steam from and at 212, since 1,221 B.t.u. are added to each pound of feed water, and 1,221 divided by 970.4 equals 1.257.

Million B.t.u.: Convenient unit for measuring large amounts of heat. One pound of steam at a temperature of 212 deg. F. and 14.7 absolute pressure contains 1,150.4 B.t.u. Therefore 869.2 lb. of saturated steam at that pressure contain 1 million B.t.u.

Balance Sheet

The waste of heat in a power plant is far more common and extensive than the waste of electric power, since any loss in the latter may readily be detected. Furthermore the possible economies in the production and utilization of steam greatly exceed the possible economies in the utilization of electric power, because the electrical conditions for any plant are more or less fixed when the apparatus is installed; but economy in the generation and consumption of steam is largely under the control of the operator.

The proper method of maintaining dependable records is to show balances between the steam produced and the steam consumed.

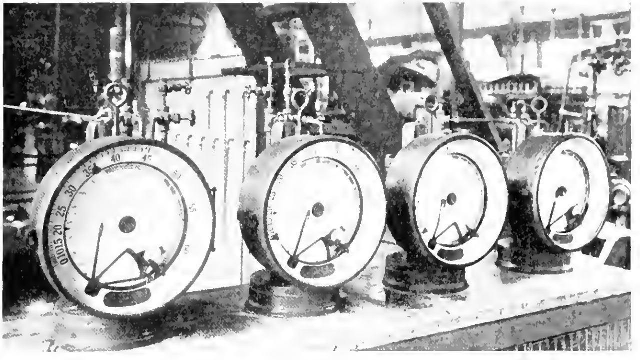


Fig. 4. General Electric Steam Flow Meters Installed in a Paper Mill

The first balance is between the amount of water supplied to the boilers and the quantity of steam the boilers produce. The second balance is between the steam produced by the boilers, available for utilization, and the steam used for the production of power or for heating and industrial purposes.

Form A illustrates a simple balance sheet for a small plant, while Form B illustrates a more complete sheet for larger plants. Fig. 1 illustrates in a simple manner the locations of flow meters to obtain information for such a balance.

Description of Balance Sheet. Form B

Lines Nos. 1, 2 and 3

There should be a line provided on the balance sheet form for each main turbine in the plant. The actual steam flow as metered should be filled in in column A, B or C, depending on the type of turbine. For example, if turbine No. 1 were a straight high pressure condensing turbine, the steam fed to it in thousand pounds would be recorded in column A. If it were a high pressure, non-condensing turbine, discharging to a heating system, the total flow to the turbine would be recorded in column B. If a turbine were run both condensing and non-condensing, both column A and column B would be filled in according to the percentage of the power generated each way. Column C should be used for low or mixed pressure turbines and should show only the low pressure steam which enters such turbines.

Columns D, E and F

In column D the total debit should be given in million B.t.u., which is calculated from the total heat in the steam above the prevailing water temperature entering the feed water heaters.

In column E a credit should be given to all machines operating non-condensing and furnishing exhaust steam which may be utilized for other purposes. If the exhaust from any non-condensing machine is too intermittent or is so contaminated with oil that it is inadvisable to utilize it, no credit could be given.

In column F the net steam chargeable to each unit or each service should be recorded. This column is simply the difference between columns D and E.

Form A

POWER PLANT BALANCE SHEET

First Balance Boiler Room	Thousand Pounds Steam per Month	
	Debit	Credit
1—Total water to boilers	100,000	
2—Blowdown from boilers		1,000
3—Steam to boiler-room auxiliaries		5,000
4—Condensation, waste and unaccounted for		1,000
5—Net steam available for utilization		93,000
6—Balance	100,000	100,000
Second Balance—Turbine Room		
7—Net steam available	93,000	
8—Converted into electric power		40,000
9—Used for heating		30,000
10—Used for industrial purposes		23,000
11—Balance	93,000	93,000

Line No. 4

Turbine room auxiliaries are treated in a similar manner to the main units. These are generally non-condensing and the exhaust steam is used to heat the feed water.

Lines Nos. 6 and 7

High pressure steam for heating should be metered and recorded in column A, since it is condensing steam inasmuch as the return is water. Where the heating steam is low pressure it may be metered and recorded in column C, or it may be estimated from turbine water rates.

Lines Nos. 9 and 10

Industrial steam, if high or low pressure, is treated in the same way as heating steam.

Lines Nos. 13, 14 and 15

The total water fed to the boilers and the steam output of each boiler should be metered. The amount of water blown down can be estimated from the time that the blow-down valves are open, if it is known how much the blow-down valves will pass per minute. If this is unknown it can be easily determined by experiment. The difference between the water fed to the boilers and the blowdown shows the net water which should have been converted into steam. This result should check the total steam output of the boilers very closely. The heat contained in this water converted into steam should be shown in the debit column I. This is calculated from the total heat in the steam above the water temperature entering the heaters.

Form B

POWER PLANT BALANCE SHEET

Steam Distribution	A [illegible]	B [illegible]	C [illegible]	D [illegible]	E [illegible]	F [illegible]
1—Turbine No.						
2—Turbine No.						
3—Turbine No.						
4—Turbine-room aux.						
5—Electric power—total						
6—Heating—high press						
7—Heating—low press						
8—Heating steam—total						
9—Industrial steam						
10—Industrial steam						
11—Industrial steam—total						
12—Total—distribution						

Steam Production	Column G Water or Steam in Thousand Pounds	Column H Eq. Steam from and at 212 Deg. F. in Thousand Pounds	Column I
		Debit	Credit
13—Total water fed to boilers	......		
14—Estimated blow-down	......		
15—Net water converted to steam	......	......	
16—Boiler-room auxiliaries	......		......
17—Used in feed-water heat, exclusive of steam from B. R. aux.	......	......	
18—Waste exhaust steam	......		......
19—General condensation	......		......
20—Unaccounted for	......		......
21—Net distributed	......		......
22—Balance	.....	.....	......

CONDENSED RECORD OF POWER PLANT USING THIS FORM OF BALANCE SHEET. AN AVERAGE DAY'S RUN

Steam Distribution for Day	Pounds
1—To turbines (by flow meters)	2,000,000
2—Industrial steam (by flow meters)	950,000
3—Station auxiliaries (by flow meters)	110,000
4—Oil pumps, thawing coal, etc. (estimated)	20,000
5—Drips, traps, radiation, etc. (estimated)	20,000
6—Total	[illegible]100,000

Steam Production for Day	Pounds Shift No. 1	Pounds Shift No. 2	Pounds Shift No. 3	[illegible] Total for [illegible]
7—Wated fed to boilers (by flow meters)	1,445,000	905,000	790,000	3,14[illegible]00
8—Blow-down	15,000	15,000	10,000	4[illegible]
9—Net water converted to steam	1,430,000	890,000	780,000	3,100,000
10—Total steam from boilers (by flow meters)	1,430,000	890,000	780,000	3,100,000

Line No. 16

The supply of all the auxiliaries in the boiler room can generally be recorded on one meter, although it is fairly accurate to include odd machines which may not be metered by calculating the steam flow from the prevailing loads and water rates. If all of the steam passing through the boiler room auxiliaries is used in heating the feed water, then there is no need for segregating this credit. Simply charge the full amount of steam to the auxiliaries, as shown in the table.

Line No. 17

If the steam to the feed water heater is not metered, as is generally the case, it should be estimated from the quantity of water fed to the boilers and the temperature elevation of the water.

Lines Nos. 18, 19, 20

Estimates should be made of the general condensation, and the balance sheet should show any waste of exhaust steam. The unaccounted for steam will be the difference between the credit and debit column necessary to make a balance.

Line No. 21

The net steam distributed is taken from the first tabulation, line No. 12, column F.

Plant records which do not show a satisfactory balance between the steam production and the steam consumption are not dependable, and the cause of the discrepancy should be carefully investigated.

Possible Losses

Many possible losses can be detected by the use of the balance sheet; for example:

1. Feed water is often heated to the maximum temperature and then overflowed because of inadequate storage capacity. The loss of heat from this case is not readily detected unless all of the steam is accounted for. Waste exhaust steam from the vent pipe of a feed water heater is commonly considered a criterion of feed water heater economies, but this is by no means true.

2. Steam traps, drip and drain piping often blow steam continuously to a sewer and there are no means of detecting it except by accounting for the steam generated and consumed.

3. In some cases the use of steam far exceeds the expected consumption. As an illustration, a certain plant introduced steam jets in the boiler furnaces and expected a very moderate steam flow. Actual records showed that the auxiliary steam consumption of the power plant was increased from 10 to 25 per cent. The steam jets were removed immediately.

4. The steam driven auxiliaries employed in power plants are frequently very inefficient, either on account of poor selection or improper maintenance. It is a mistake to use wasteful auxiliaries on the assumption that the heat in the exhaust steam is used in the feed water. High pressure steam or extracted steam from the main units should be used to augment the deficient supply of steam for the feed water. There is then an opportunity of regulating the feed water temperature or of reducing the waste for all conditions of load.

5. Loss by radiation is a considerable factor and should be carefully estimated with a view to reducing it as much as possible by the application of proper lagging on pipes and machines.

Ways and Means of Metering

Each station presents special problems for the installation of flow meters and it is therefore advisable to consider which arrangement of meters and form of balance sheet are best suited for the exisiting conditions.

The common practice is to meter the high pressure steam to each turbine. This is quite satisfactory for a straight non-condensing or condensing turbine, but in the case of a low-pressure, mixed pressure or extraction turbine, the relative flows of low and high pressure steam can be more accurately determined by metering both the high pressure steam to the main unit and the condensate from the condenser. This recommendation applies to units employing surface condensers.

There is no objection to metering all of the power house auxiliaries as a unit, providing those used in the turbine room can be segregated from those used for steam production. A common method is to provide one flow meter for boiler room auxiliaries and another flow meter for turbine room auxiliaries.

The metering of boiler feed is generally accomplished by installing a flow meter on the discharge of each boiler feed pump. In the case of reciprocating pumps sufficient air chamber space, together with pressure throttling between pump and point in line where meter is connected, is necessary to obtain accurate readings.

Advantage of Metering Boiler Outputs

All of the advantages accruing from the use of flow meters showing the output of each boiler are not generally recognized. In some plants the water fed to each boiler is metered, but the prevailing practice is to meter the steam generated by each boiler. Some of the advantages of getting a record of the individual boiler outputs are:

1. Every boiler has a most efficient point in the operating curve and this is generally from boiler rating to 175 per cent rating. Assuming that the most efficient point of the boiler is known, how can an operator maintain the boiler at its most economical capacity without a meter record?

2. In order to check the regular overall boiler and furnace efficiency (the results of this check being far more valuable than special tests), the amount of steam produced by a boiler each month should be checked by the amount of coal consumed.

3. Meter records will show the relative values of different kinds of boilers, stokers, methods of baffling, methods of firing, etc., both as to capacity and economy.

4. It is common practice to compare the results obtained by the firemen on different shifts and to change the shifts from night to day so that each set of firemen will have an opportunity of working on the same load conditions.

5. Individual boiler flow meters indicate whether a fireman is doing his part of the work. There is a tendency for a man to sacrifice ouput for the sake of maintaining good efficiency or a high CO_2 content in the gas.

6. A record of what each boiler is capable of doing for the prevailing and for emergency conditions is especially valuable when trying to ascertain if additional boiler capacity is required. To illustrate this point, a certain company was contemplating the expenditure of several hundred thousand dollars for new boilers until it was found that the existing boilers were operating at only 65 per cent of rated capacity.

In general, how can a fireman be expected to learn to operate a boiler and stoker to the best advantage without affording him a continuous record of the steam output? This point is well covered by the following quotation from an editorial appearing in one of the engineering magazines:

"No one would expect the electrical end of a plant to be operated satisfactorily without some instruments to guide the operators. Yet the pressure gauge and the water column have been and are about all the average boiler attendant has to help him. For the rest he is supposed to be able to get along by using his eyes to judge the condition of the fire. There are some men naturally gifted who can do fairly well under even these circumstances, but why leave to human judgment a problem that is easily simplified until it is no trick at all by providing a few thermometers, a steam flow meter on each boiler, and a draft gauge.

"There is nothing mysterious about burning coal so as to get the most heat out of it where and when it will do the most in turning water into steam, but it cannot be done continuously and consistently without the means mentioned to show the firemen when it has happened, and if it has not, why."

The maintenance of accurate records showing the steam generated and consumed as well as the water supplied to the boilers is essential for the economical management of central stations and manufacturing industries. Without such records serious losses will probably be undetected.

Why not follow the example of hundreds of companies both in this country and abroad? Eliminate guess work, meter steam and water as we do electricity, use the form of balance sheet best suited to the particular plant, and save money by the lower cost of operation.

A New Type of Definite Time Control Relay

By A. B. Campbell

Experimental Laboratory, General Electric Company

Exact duplication of exposure in X-ray work is often desired and where the interval of time is short the personal element is apt to introduce a large error where exposures are made by hand. Two of the devices described in this article were developed to do away with this large variable through automatic control. Exposures ranging from a fraction of a second to thirty seconds are made automatically and the error is only a few per cent even with the short time settings. The third relay described is employed for automatically timing the operation of induction motors.—Editor.

The definite time control relays described in this article were originally developed for the definite time control of induction motors operating from automatic starting compensators. In these installations it replaces the bellows type of definite time relay and is a decided improvement for this service.

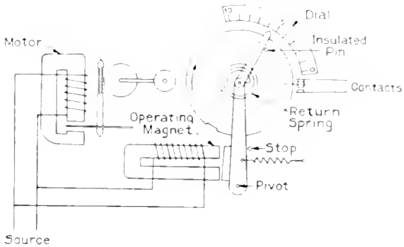


Fig. 1. Diagram Showing Principle of Operation of Time Control Relays

These relays were found to possess the characteristics required in a switch for automatically timing X-ray exposures, and as an automatic timing device was required to complete the portable X-ray sets being developed by the Company, the industrial control relays were modified for the purpose, the changes involving only minor details.

X-ray Tube Relays Type MC-1

The principle of operation of the relays is shown by the schematic diagram of Fig. 1, while the appearance of the several types is shown in Figs. 4 and 5. Reference to Fig. 1 shows that the operation consists in allowing a set of contacts to be mechanically operated after a definite time interval by an insulated pin. This pin is carried on a large gear which is driven through a suitable reduction at constant speed by a very small induction motor of the disk type. Energizing the device causes the large gear carrying the pin to mesh with the pinion connecting with the motor through the worm wheel. At the same instant the motor starts and drives the pin to the operating point in a time depending on the lever setting. If the relay remains energized after the contacts have been opened, the motor continues to run, but since the large gear has a mutilated portion which engages the pinion at this point the contacts are held open until the motor is de-energized, thus stopping the motor and releasing the

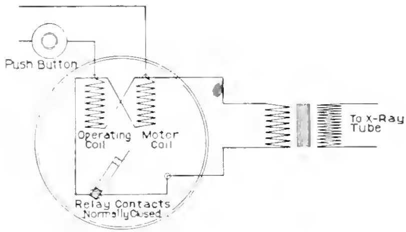


Fig. 2 Connection Diagram of Low Capacity MC-1 Relay

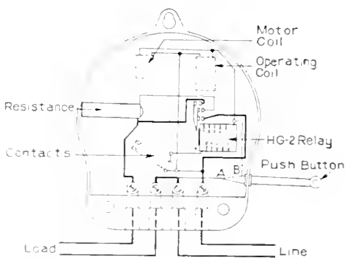


Fig 3. Connection Diagram of High Capacity MC-1 Relay with Auxiliary Relay

armature that controls the mesh of the large gear and allowing the insulated pin to return to its initial position against the time lever. Different time intervals may be obtained by shifting the time lever to various parts of the scale.

In service these relays are connected directly in the primary circuit of the X-ray tube transformer. The switch controls contacts which are directly in series with the primary and are normally closed. Energization of the tube and relay is controlled by a manually operated switch or push button. After a lapse of time, depending on the dial setting of the relay, the relay contacts are opened and the transformer is de-energized. The line switch or push button is then released opening the relay circuit. A diagram of connections is shown in Fig. 2. As built for the portable X-ray sets the switch has a maximum time setting of thirty seconds, the dial being graduated in one second divisions.

Fig. 4. Low Capacity MC-1 Relay

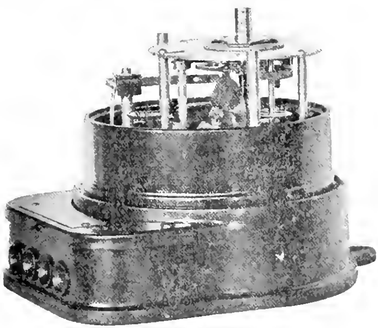


Fig. 5. High Capacity MC-1 Relay with Auxiliary Relay Mounted in Base

The low capacity switch is designed for use with tubes having a maximum rating of 10 milliamperes. The high capacity tubes requiring heavier primary currents are taken care of by an instantaneous acting relay controlled by the time switch. This additional relay is contained in a sub-base and is mounted directly below the time switch forming a complete unit. This construction is clearly shown in Figs. 5 and 6, and the connections in Fig. 3.

Fig. 6. Under Side of High Capacity MC-1 Relay Showing Auxiliary in Base

The high capacity switch can be used with tubes rated 50 milliamperes and requiring a maximum of about 75 amperes in the primary circuit of the transformer, and is controlled either by a series line switch or a push button. The high capacity switch is fitted with a dial which gives a maximum time setting of ten seconds, being divided into one-quarter second divisions.

Both the push button in low capacity outfits and the auxiliary relay in the high capacity units are provided with a series resistance which is temporarily in circuit to prevent a high initial rush of current.

Induction Motor Relay (Type MC-2)

The general construction of the MC-2 relay is shown in Fig. 7. This type of time switch is designed to operate in connection with automatic starting compensators controlling induction motor operation and therefore has a different arrangement of contacts from the X-ray time switch, the mechanical construction otherwise being exactly the same. The contact arrangement and the circuit diagram for the MC-2 relay are shown in Fig. 8. Due to the necessity for having a

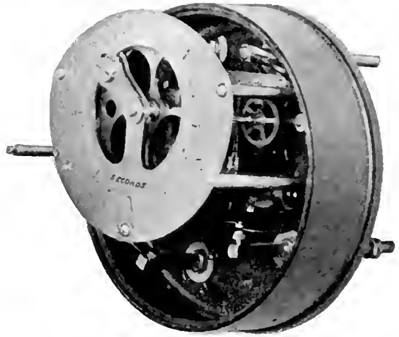


Fig. 7. MC-2 Relay for Automatic Time Control of Induction Motors

quick break contact mechanism, a trigger arrangement has been provided which gives a practically instantaneous change-over from starting to running compensator coils. The cycle of operation when used with the automatic starting compensator panel is:

Depressing the start button short circuits the holding contacts of the relay, thereby energizing the device permanently. By the same operation the circuit through the starting coil of the compensator is completed. After a definite time interval, depending on the relay setting, the tripping mechanism is operated by the gear train, allowing the common contact *B* from the line terminal to instantly shift from the contactor starting coil to the running coil, due to its own spring tension. The remainder of the contactor running coil circuit is completed through the usual lock-out switch provided on the starting compensator, which is closed only after the starting compensator is completely open, thus preventing both the starting and running contacts from being closed on the auto-transformer at the same time. As this switch is on the line continuously, the large gear has not been mutilated as in the MC-1 switch, and the motor is allowed to stall against the tripping mechanism after operation until potential is removed from the device by an external switch.

On account of the wide variation in intervals desired, two standard interval capacities have been designed, giving full scale for 90 seconds and 25 minutes.

Tests

The following tests have been made on five MC-1 X-ray switches from production, and give a general idea of the operating characteristics of these devices:

MC-1 Relay: Voltage Error

Per cent of normal time at 110 volts

Relay	100 Volts	110 Volts	120 Volts
52358	104.6%	100%	94.6%
52373	102.6%	100%	95.6%
Average ..	103.6%	100%	95.1%

Thus a variation in voltage of 9 per cent shows 3 to 5 per cent variation in time interval.

An MC-2 relay was connected to a 440-volt, 60-cycle panel as shown in Fig. 8, the start and stop push buttons being operated by cams driven from a small series motor at a speed to give one revolution every 7 to 8 seconds. After 100 hours' operation, a total of about 46,500 individual operations, the device had not shown any appreciable wear on bearings or contacts.

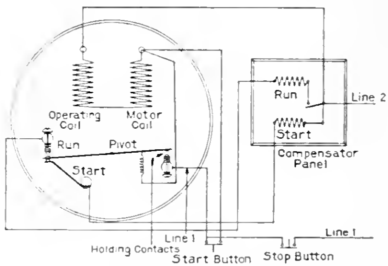


Fig. 8. Connection Diagram of MC-2 Relay with Start and Stop Push Button Control

Conclusions

In construction the MC-1 and MC-2 relays are very similar, the principal difference being in the contact arrangement and coil windings.

MC-1 X-ray Switch: Accuracy of Repeat

30 seconds interval relay, 110 volts, 60 cycles

Setting	Repeats 1	2	3	4	5	6	Max. Error Per Cent
30 sec.	30.4	30.6	30.6	30.48	30.70	30.6	+2.3
15 sec.	14.93	14.93	15.01	14.77	14.85	14.88	−1.5
5 sec.	5.16	4.99	4.97	5.03	4.91	5.01	+3.2
1 sec.	0.98	1.02	1.033	1.00	0.967	1.033	∓3.3

MC-2 Relay: Accuracy of Repeat

90 seconds interval relay, 220 volts, 60 cycles

Setting	Repeats 1	2	3	4	5	6	Max. Error Per Cent
90 sec.	90.6	90.6	90.5	90.0	91.0	91.5	+ 1.7
30 sec.	30.2	29.6	29.8	30.0	30.0	30.0	− 1.3
15 sec.	15.0	14.2	15.0	14.8	15.0	15.0	− 5.3
5 sec.	5.33	5.28	5.25	5.33	5.25	5.25	+ 6.5
3 sec.	2.62	2.55	2.38	3.17	3.40	3.23	−20.6

The time interval in both relays is established by a constant speed induction motor of the disk type having very small frequency and voltage errors. A change in time interval may be made by simply shifting a pointer over a graduated dial.

Tests show that the energy required in the MC-1 relays is about 8.5 watts and about 9.0 watts for the MC-2 relay.

An error due to the relative position of the teeth on the large gear and pinion at instant of mesh is always present and appears as a larger percentage at low scale settings, but is relatively unimportant.

Due to the low torque requirements and the comparatively low speeds used the wear on parts is negligible, as shown by the life test in normal service.

Relays for other frequencies than 60-cycles are available. They show practically the same characteristic as the 60-cycle devices described.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Balancing
Balance of High-Speed Electric Dynamos and Motors. Wheeler, H. D.
Elec'n (Lond.), July 29, 1921; v. 87, pp. 136-138.

Ball Bearings
Anti-Friction Bearings in the Steel Mill. MacCutcheon, A. M.
Assoc. Ir. & St. Elec. Engrs., Sept., 1921; v. 3, pp. 321-350.
(Discusses the subject as it applies to the electric motor.)

Cars, Electric
Tendency in Train Operation. Woods, G. M.
Elec. Rwy. Jour., Sept. 10, 1921; v. 58, pp. 395-397.
(Statistical analysis of costs of operation of motor bus, trolley bus and safety car.)

Condensers, Steam
Electrical Method of Detecting Surface Condenser Leakage. Caldwell, W. E.
Power, Aug. 9, 1921; v. 54, pp. 217-219.
(Based on a scheme for measuring the electrical conductivity of the condensate.)

Electric Cables
Heating of Cables. Dunsheath, Capt. P.
Elec'n (Lond.), Sept. 9, 1921; v. 87, pp. 318-320.
(Theoretical paper.)

Industrial Underground Cables. DeMuth, W. B.
Power Pl. Engng., Aug. 1, 1921; v. 25, pp. 758-759.
(Factors affecting reliability and heat dissipation.)

Electric Conductors
Economy of Substituting Copper for Iron Wire. Rush, H. S.
Elec. Wld., Sept. 10, 1921; v. 78, pp. 515-517.
(Gives test data to show when it is economical to substitute copper for iron.)

Electric Drive—Steel Mills
Power-Factor Correction in Steel Mills. Sels, Hollis K.
Elec. Jour., Sept., 1921; v. 18, pp. 419-424.

Electric Drive—Textile Mills
Variable-Speed Motors in Finishing Plants. Lewis, Warren B.
Mech. Engng., Sept., 1921; v. 43, pp. 589-592.
(Shows saving produced by substitution of motors for steam-engine drive.)

Electric Motors, Induction
Synchronous-Induction Motor Manufactured by Oerlikon, Switzerland. (In French.)
Génie Civil, Aug. 13, 1921; v. 79, pp. 150-153.
(Describes the construction and applications of a type of motor said to combine the desirable features of synchronous and of induction motors.)

Electric Motors—Speed Control
Variable Speed Induction Motor Sets. Kincaid, C. W.
Elec. Jour., Sept., 1921; v. 18, pp. 385-389.
(A general discussion of the Kramer, the Scherbius and the frequency converter systems.)

Electric Motors—Starting Devices
Some Recent Developments in Induction Motor Starting. Spencer, Millard C.
Assoc. Ir. & St. Elec. Engrs., Sept., 1921; v. 3, pp. 415-425.

Electric Motors, Synchronous
Synchronized Induction Motor. Genkin, V. (In French.)
Revue Gén. de l'Elec., Aug. 6, 1921; v. 10, pp. 187-190.
(On the theory of operation of a special type of combined synchronous and induction motor.)

Electric Power
Electrical Transmission vs. Coal Transportation. Smith, Harold W.
Elec. Jour., Sept., 1921; v. 18, pp. 402-404.

Electric Transmission Lines
Graphic Method for the Study of A.C. and D.C Net works. Le Cocq, R. (In French.)
Revue Gén. de l'Elec., Sept. 3, 1921; v. 10, pp. 283- 289.
(Mathematical treatment.)

Quick Line Calculation Without Charts or Tables. Burt, Austin.
Elec. Wld., Aug. 27, 1921; v. 78, pp. 417-419.
(An approximate method.)

Electrical Machinery—Parallel Operation
Unstable Operation of Generating Stations in Parallel. Higgins, D. D.
Elec. Wld., Aug. 27, 1921; v. 78, pp. 414-416.
(Results of tests.)

Voltage Characteristics of Direct-Current Generators and Their Bearing on Parallel Operation. Thompson, Eustis H.
Power, Aug. 23, 1921; v. 54, pp. 287-290.

Electrical Machinery—Temperature
Generator Operating Temperatures. Mortensen, S. H.
Power, Aug. 30, 1921; v. 54, pp. 319-320.

Electrical Machinery—Testing
Regenerative Method of Testing Electrical Machinery. Cotton, H.
Beama, Aug., 1921; v. 9, pp. 127-136.
(Describes methods and shows diagrams of connections for testing different classes of electrical machinery by regeneration.)

Fatigue of Metals

Improvements in Methods of Fatigue Testing. Gough, H. J.
Engr. (Lond.), Aug. 12, 1921; v. 132, pp. 159-162.
(Describes tests and shows illustrative test results in tabulated and graphic form.)

Forging

Forging of Arc Deposited Metal and Arc Welds. Escholz, O. H.
Weld. Engr., Aug., 1921; v. 6, pp. 26-29, 40, 42

Gears, Reduction

Mechanical Reduction Gears on Warships and Merchant Ships. Macalpine, John H.
Am. Soc. Nav. Engrs. Jour., Aug., 1921; v. 33, pp. 552-568.
(A discussion of two earlier papers on the same subject.)

Turbine Reduction Gears Versus Electric Propulsion for Ships. Berg, Eskil.
A. I. E. E. Jour., Sept., 1921; v. 40, pp. 724-729

Hydroelectric Development

Government Engineers Report on St. Lawrence Waterway. Roby, Harrison G.
Engng. News-Rec., Sept. 8, 1921; v. 87, pp. 402-406.
(Engineering features. Includes special insert showing maps, profiles, etc.)

Inductive Interference

Electrification May Interfere with Communication. Schuler, H. W.
Rwy. Elec. Engr., Sept., 1921; v. 12, pp. 354-360.
(Lengthy article by an electrical engineer of the Swiss Federal Railways. Shows results of interference tests on electrified Swiss railways.)

Noises, Machinery

Noise Created by Electrical Machinery. Fritze, Hubert. (In German.)
Arch. fur Elek., July 23, 1921; v. 10, pp. 73-95.
(Theoretical treatment of causes and elimination of noise.)

Radio Communication

Application of Radio Communication to Public Utility Purposes. Iler, George A.
Elec. Trac., Aug. 15, 1921; v. 17, pp. 509-512
(Short description of method and apparatus used by the Georgia Railway & Power Company.)

Railroads—Electrification

Electrification of the Steel Plant Railroad. Gerhardt, R. B.
Assoc. Ir. & St. Elec. Engrs., Sept., 1921; v. 3, pp. 277-291.
(General discussion of its possibilities.)

Ship Propulsion, Electric

Electric Ship Propulsion. Butler, R. J.
Elec'n (Lond.), July 29, 1921, v. 87, pp. 126-130.
(Gives a detailed table of ships that are electrically propelled. A summary of the present day situation.)

Skin Effect

Skin Effect in Large Stranded Conductors at Low Frequencies. Middleton, W. I. and Davis, E. W.
A. I. E. E. Jour., Sept., 1921; v. 40, pp. 757-763.
(Theoretical paper with tables showing test results.)

Steam Turbines

Some Recent Developments in Large Steam Turbine Practice. Baumann, K.
I. E. E. Jour., June, 1921; v. 59, pp. 565-663
(An exhaustive paper, with many illustrations, graphs and statistical tables.)

Steam Turbines, Marine

Low Pressure Turbine Blading Failures in Destroyers. Ducey, Lieut.-Comdr. D. F.
Am. Soc. Nav. Engrs. Jour., Aug., 1921; v. 33, pp. 512-540.
(Illustrated paper concerned with typical blade failures and with tests of blades.)

Superheaters

Steam Superheaters. Pratt, Arthur D, and others
Engrs. Club of Phila. Jour., Aug., 1921; v. 38, pp. 291-308.

Switches and Switchgear

Magnetic Force in Disconnecting Switches. Dwight, H. B.
Elec'n (Lond.), Sept. 2, 1921; v. 87, pp. 290-291.
(Calculates the forces set up.)

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Some Effects of Vibration on Electrical Machinery. Rankin, K.
Power Pl. Engng., Sept. 1, 1921; v. 25, pp. 861-862.

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Engineers and the Price System. Veblen, Thorstein. 169 pp., 1921, N. Y., B. W. Huebsch, Inc.

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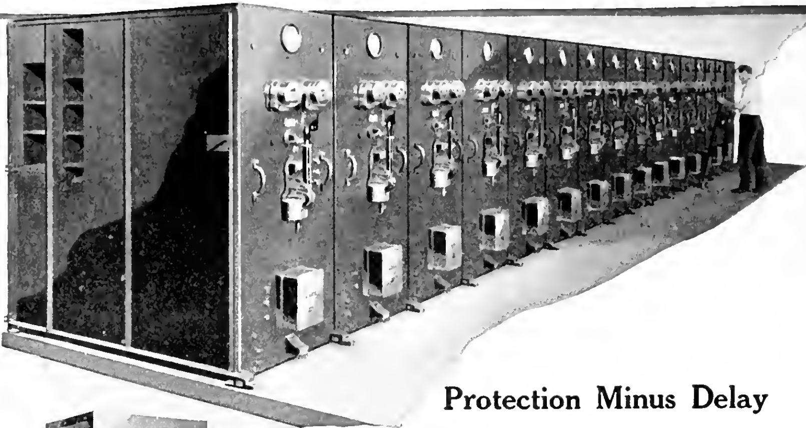

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GENERAL ELECTRIC REVIEW

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DECEMBER, 1921

U. S. S. *TAMPA*, FIRST ELECTRICALLY PROPELLED COAST GUARD CUTTER

GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE — Editor, JOHN R. HEWETT — Associate Editors, B. M. EOFF and E. C. SANDERS
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High intensity Factory Illumination with 500-watt Bowl-enameled Mazda Lamps and R. L. M. Reflectors
(See Article, Page 1023)

GENERAL ELECTRIC REVIEW

THE ELECTRIFICATION OF MERCHANT SHIPS

During the last year we have devoted considerable space to the general subject of Marine Engineering. Our issue of February was devoted entirely to marine matters and the reception accorded that issue indicates the interest taken in the subject. In this issue we publish an article on the Electrification of Merchant Ships and we hope to publish more articles under this general heading in subsequent issues.

The great activity in shipbuilding caused by the war has led to many changes in both the ships of the U. S. Navy and in the merchant marine. Progress made in marine engineering during the last decade has made it certain that the faithful old reciprocating marine engine has served its day and that it is now to be displaced by the high speed steam turbine. With the high speed turbine a ship may be propelled through the medium of reduction gears or by electric motors. The remarkable program of the U. S. Navy shows what faith is placed in the all-electric ship for fighting purposes. No doubt the number of large merchant ships and passenger vessels to be propelled by electric motors will increase each year. But there is still a considerable field where gears will be used as a means of reducing the speed between the turbine and the propeller shaft. The Diesel electric equipments are also likely to become more common than they are at present.

Whatever the type of propelling equipment may be all types of vessels will use electrical auxiliaries to an increasing extent as manufacturers are prepared to furnish electrically driven pumps, air compressors, refrigerating machinery, forced draft blowers and ventilators, all specially designed for marine service. Besides these, thoroughly reliable motors, which can meet the severe requirements of marine service, have been developed for the operation of such deck machinery as the mooring winches, anchor winches, capstans, cargo winches and steering gear. All these devices can be operated better and more efficiently by electric motors than by steam.

In connection with the electrification of merchant ships the maiden trip of the electric merchantman S. S. *San Benito* is of special interest.

The S. S. *San Benito* was built by Workman, Clark & Co., of Belfast, for the United Fruit Line. Her tonnage is 5500, her length 336 ft., and her beam 45 ft. She was designed for a speed of 12.5 knots.

The most interesting feature about the *San Benito* is that she is propelled electrically. Her main generating unit consists of a 2040-kw. Curtis turbine generator and the propeller is driven by a 3000-h.p. synchronous motor. This equipment was built by the British Thomson-Houston Company. Her circulating pumps, forced air draft and ventilating system are all electrically operated.

The *San Benito* arrived in New York on October 24th on her maiden trip across the Atlantic. The trip was in every way successful, although she encountered a cyclone and was tossed about for 24 hours consecutively in an unusually heavy sea.

Captain J. C. Jackson in command of the vessel said that it was the worst storm he had encountered in his 29 years at sea. As such interest is centered in the behavior of this all-electric merchantman, Captain Jackson's remarks are well worth quoting.

"Ordinarily under such terrible storm conditions we would have had all sorts of trouble with our propeller racing but with this electric drive we did not experience any such trouble. I have never been on a ship that acted so well under all conditions. During those 24 hours we were in the storm, the propeller was out of the water as much as she was in but there was not the slightest evidence of any racing. Another feature which impressed me was the absence of vibration. Sometimes I actually had to look out the port holes to see if we were moving, so smooth and quiet did this electric drive operate. Truly, this is the finest ship I have been on in my many years at sea."

Chief Engineer R. Crumley was just as enthusiastic. "There is absolutely no comparison of the electric drive with the reciprocating engine. I have been at sea since a boy 14 years old and this beats anything I have ever seen or experienced. Hitting that cyclone she couldn't have been given a better all around test."

Among the 28 passengers on the *San Benito* was Mr. W. McClelland, Director of Electrical Engineering of the British Admiralty. He was very pleased with the behavior of vessel and said he had never seen anything more reliable in his life than the electric drive. J. R. H.

The Respective Fields of the Rail Car, Trolley Bus, and Gasoline Bus in City Transportation

By J. C. Thirlwall

Railway and Traction Engineering Department, General Electric Company

The trolley bus, although used fairly extensively in England, Germany, and Austria, is a new development in American transportation. During the past few months, experimental demonstrations of these vehicles have been given in Richmond, Norfolk, Philadelphia, and Detroit, and two are now in commercial operation in New York City. "Trackless Transportation" is being investigated by a committee of the American Electric Railway Association, and this article is a contribution to their study of this subject.—Editor.

Many railway officials who have been searching diligently for means to reduce operating costs and secure needed increase in revenue are demanding accurate information as to the conditions under which the ordinary trolley car, the trackless trolley bus, and the gasoline bus can be used to the best advantage. The relative costs of carrying passengers in these different types of vehicles is also of considerable importance

In this article the writer has tabulated the respective costs on a comparative basis for a variety of conditions. In general, the calculations indicate that:

(a) Where rush-hour headways of three minutes or less are required with safety cars, rail cars are the most economical and up to six-minute headways offer successful competition to the other types where the road is a going concern.

(b) On longer headways the trolley bus appears to have the advantage due to lower fixed charges.

(c) The gasoline bus on account of higher operating expense does not offer competition to the rail car until minimum headways of 10 minutes are reached on new routes and 20 minutes on existing lines.

(d) The trolley bus is more economical than the gasoline bus up to headways of 60 minutes or longer.

A tabulation of the respective fields is as follows:

Minimum headways, 3 minutes or less; rail cars

Minimum headways, 3 to 6 minutes; rail cars or trolley bus

Minimum headways, 6 to 60 minutes; trolley bus

Minimum headways, 60 minutes or more; gasoline bus.

Of course, as the tabulations show, the difference in favor of the trolley bus as compared to the rail car operating on headways of seven and one-half or ten minutes on an existing route is too small to warrant even the suggestion that rails and equipment should be scrapped and replaced with the new form of transportation. It is not until minimum headways of 15 or 20 minutes are reached that the estimated saving of the trolley bus over an existing rail route becomes sufficient to justify such a suggestion.

To illustrate these conclusions and to show the premises on which they are based, a number of tables have been prepared, and are presented subsequently, in which a direct comparison is made of the elements of investment cost for a rail system and for the two types of buses. The actual cost of laying rail in paved streets, of erecting overhead trolley lines, or of building power stations, substations or shops varies considerably as between different localities, but the unit costs used in the tabulations are believed to represent fair averages for present construction.

For instance, a figure of \$60,000 per mile has been taken for single track with few turnouts laid in a paved street, \$75,000 for single track with more turnouts for shorter headways, \$100,000 as about the lowest estimate for a route-mile of light double track for safety cars, and \$120,000 for a route-mile of heavy track for double-truck cars. In some localities tracks may be laid for less than these figures; in most large cities they would be considerably exceeded; but they are believed to indicate with a fair degree of accuracy the magnitude of the biggest item of investment that can be saved by the use of the rubber-tired vehicle.

Overhead trolley lines using wooden poles with cross spans can be erected for about \$5000 a mile where only one trolley wire and no feeders are required, and for double track with ordinary feeders should not exceed \$6000 per route-mile. The two-wire trolley required for trolley buses costs about \$500 per mile more than the ordinary type of construction; \$1000 more per mile when the line is run on both sides of the street. The transmission line is estimated at \$3500 per mile.

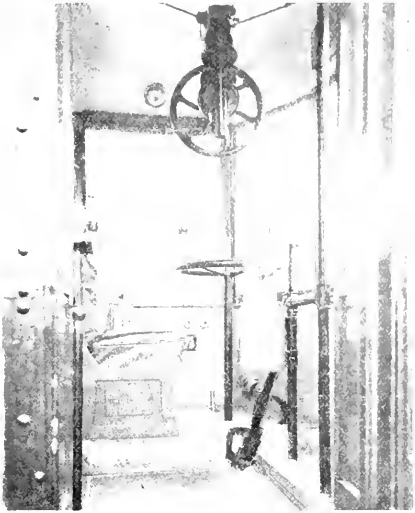


Fig. 1. Trackless Trolley Showing Operating Cab, Foot Pedals for Operating Controller and Brake and Controlling Apparatus for Collector

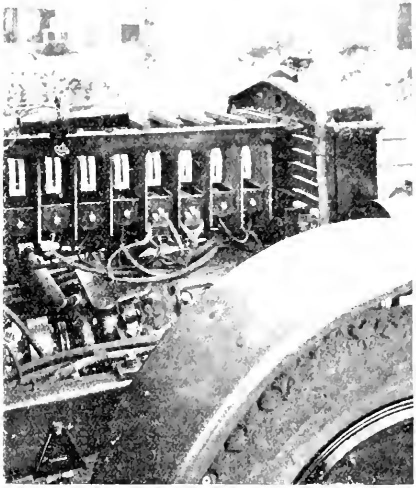


Fig. 2. Contactor Control and Motor Equipment for Trackless Trolley

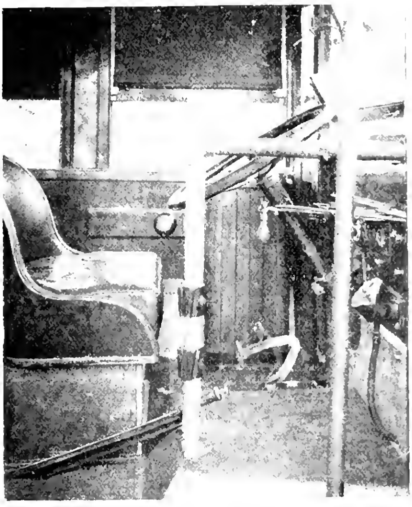


Fig. 3. Foot-operated Master Controller Mounted on Trackless Trolley. Two G-E 258 Motors

Fig. 4. Interior View Trackless Trolley, Seating Capacity 30 Persons, Equipped with G-E Railway Motor Controller and Collecting Device

and it is assumed that the length of the transmission system is half that of the distribution lines.

A summary of these and other unit cost figures is shown in Table I.

TABLE I

AVERAGE CONSTRUCTION COSTS

Single track per route-mile....	$ 60,000 to	$ 75,000
Double track per route mile...	100,000 to	120,000
Trolley lines per route-mile...	5,000 to	6,500
Transmission line per route-mile..........	1,800	
Generating station per maximum kw. output.........	125	
Substation per maximum kw. output	40 to	50
Shops per car used	1,500 to	2,500
Double-truck cars	12,000	
Safety cars	6,300	
Trolley buses	8,000	
Gasoline buses..	8,000	

The rail car requires an investment in each of the items; the trolley bus dispenses with the track, but necessitates the use of all other details; the gasoline bus requires an investment in the vehicles themselves, and in storage and shop facilities, but eliminates the remaining construction charges.

On fairly long headways, i.e., from 8 to 20 minutes, the fixed charges on the rail route will exceed the operating costs, and even on

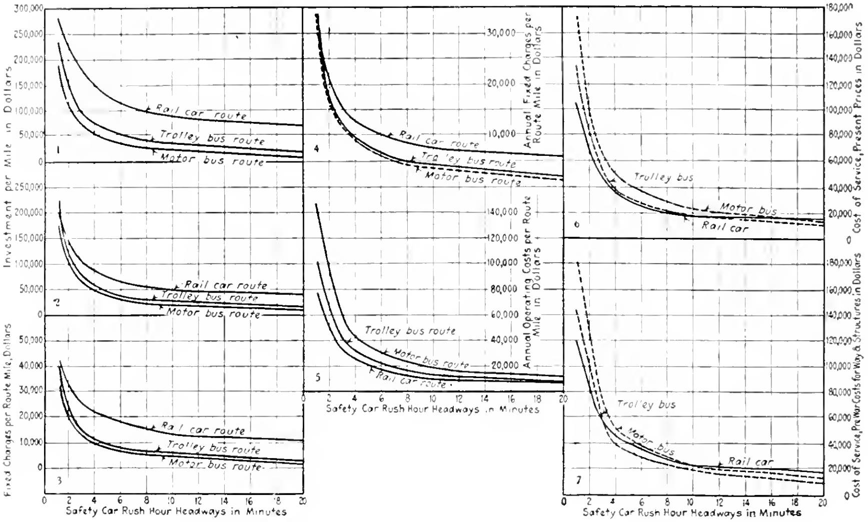


Fig. 5. Graphical Cost Analysis of Rail Car, Trolley Bus, and Gasoline Bus

Curves 1—Present day investment per mile of route for rail service compared to investment for bus service of equal capacity

Curves 2—Investment per mile of route for rail service based on pre-war costs for track and structures and present costs for rolling stock compared to the investment per mile of route for bus service of equal capacity

Curves 3—Annual fixed charges per route-mile based on present construction costs

Curves 4—Annual fixed charges per route-mile based on pre-war costs for track and structures and present costs for rolling stock

Curves 5—Annual operating costs per route-mile for rush-hour rail service. Headways compared to bus service of equal capacity. Longer headways during normal hours

Curves 6—Total annual operating costs and fixed charges per mile of route based on pre-war costs for way and structures and present costs for rolling stock

Curves 7—Total annual operating costs and fixed charges per mile of route based on present construction costs

a heavy traffic route, they will amount to 40 per cent of the total costs of operating the line. The handicap of these heavy investment charges has given the gasoline bus its opportunity and enabled the jitneys to compete successfully in many instances with the established traction lines. The gasoline bus has a higher power bill and a higher maintenance cost than the safety car, and the depreciation of its driving equipment is

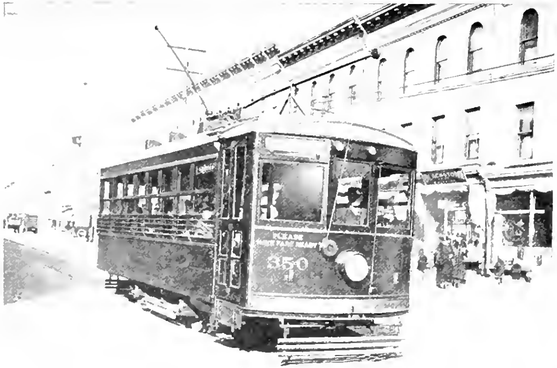


Fig. 6. Light-weight Safety Car Equipped with G-E 258 Railway Motors and K-63 Control. Brooklyn Rapid Transit System, Brooklyn, N. Y

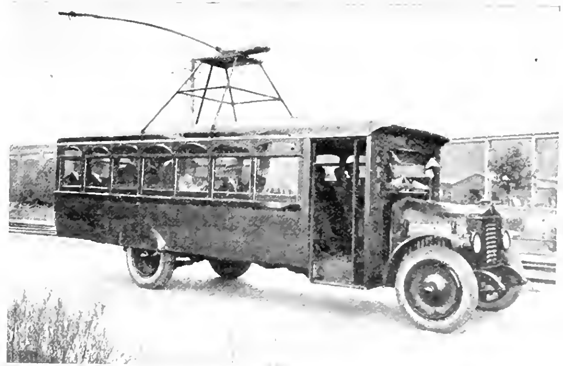


Fig. 7. Trackless Trolley Equipped with Two G E 258 Motors. Foot control and General Electric collector

Fig. 8. Trackless Trolley Equipped with G E Railway Motor Controller and collecting device

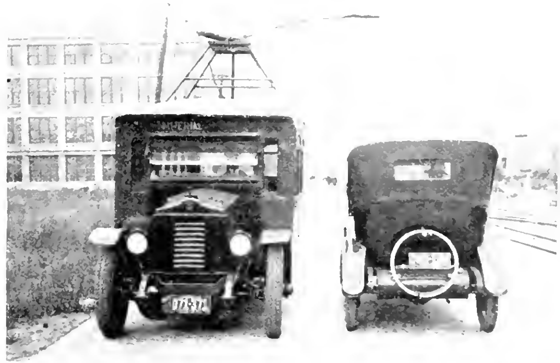


Fig. 9. Trackless Trolley Equipped with G-E 258 Motors. Foot-operated contactor control and G-E sliding collector

decidedly more rapid than that of electric motors and control on the rail cars; but even so, for many conditions of traffic it is the more economical of the two methods of transportation. However, its proponents have frequently tried to force it into classes of service where its higher operating costs far outweigh its saving in fixed charges. Under such conditions it can only continue to operate by evading the responsibilities of good service and not attempting to provide the necessary extra equipment for properly handling the traffic peaks morning and night for which every traction company is expected to equip itself.

Table II is a comparison of operating costs per car-mile for four classes of cars. The rail car data are the average of the actual records of a number of companies using both safety cars and double-truck cars; the gasoline bus costs are derived from the records of five representative bus companies, Table III. Three of these use small cars seating less than 23 passengers; for these the gasoline and oil costs have been adjusted to a weight of 10,000 lb.; and for two companies corrections have been made on the basis of using solid instead of pneumatic tires.

The costs of the trolley bus are assumed to be the same as the safety car and the gasoline bus as regards transportation charges and general expenses; its maintenance of way and structure covers repairs and renewals on the overhead trolley lines only; its maintenance of equipment is based on the body and chassis and tire expense of the gasoline car, and motor and control maintenance of the safety car. For instance, safety cars on an average cost only 1.7 cents per car-mile to maintain, of which only about 0.6 cents are for repairs to the electrical equipment. The gasoline buses cost on an average 8.5 cents, of which 2.0 cents goes for the maintenance of solid tires, 1.5 cents for the body and truck, and 5 cents for the engine and transmission.

The trolley bus would presumably have the same cost for tires, body, and truck upkeep, but only 0.5 cent for the motors and control, making its total maintenance 4 cents per mile or 4.5 cents less than the gasoline vehicle.

On the power account, due to higher friction, the trolley bus will take more power per ton-mile than the rail car, but its lighter weight will somewhat more than offset this and make its total power cost a trifle less than that of a safety car. A gasoline bus weighing 10,000 lb. in frequent stop service can make only about 4 miles to a gallon of gasoline, or 5.5 cents per mile, and oil and grease add about 1.5 cents additional; it has therefore a total power expense of 7 cents per mile or 4.7 cents more than the trolley bus.

TABLE II

OPERATING COSTS IN CENTS PER CAR-MILE

	52-Pass. Rail Car 36,000 lb.	32-Pass. Safety Car 16,000 lb.	30-Pass. Trolley Bus 10,000 lb.	30-Pass. Gasoline Bus 10,000 lb.
Maintenance of way and structure	3.0	2.0	0.7	0.0
Maintenance of equipment	3.4	1.7	4.0	8.5
Power	5.9	2.5	2.3	7.0
All other expenses	19.0	12.0	12.0	12.0
Total operating expense	31.3	18.2	19.0	27.5

The depreciation of a gasoline bus is recognized to be much more rapid than that of a rail car; apparently this is due to the comparatively short life of its engine and transmission. The economic life of a rail car and its equipment is at least 15 years. There is no reason to doubt that the body and truck of any well built bus should last that long. But from all records available, the gas engine and transmission have a life of not over 4 to 5 years, and since their first cost is about 25 per cent of the equipped bus, the total depreciation is considerably higher than for the electric car. We have taken them respectively at 4.6 per cent for the rail car and the trolley bus, and at 8 per cent for the gasoline bus.

As shown in Table IV, the total fixed charges on the rail system are assumed to be 15 per cent; 9 per cent for interest, 2.8 per cent for taxes and insurance, and 3.2 per cent for depreciation on the entire physical property. Since the cost of cars, with their comparatively short life, is a bigger proportion of the total investment in a trolley bus installation, depreciation is figured at 3.7 per cent and the total fixed charges at 15.5 per cent. For the gasoline bus installation, for the foregoing reasons, total depreciation is figured at 6.9 per cent and total fixed charges at 18.7 per cent.

In Tables V to XI, the upper figures are based on entirely new construction at today's prices; the lower apply to the company which can use track, overhead, stations, and shops constructed at pre-war values assumed to be 50 per cent lower than at present.

In every case, except Tables X and XI, we assume a greater number of buses than rail cars would be required for rush-hour service, on the assumption that a modern double-truck rail car can carry 120 passengers without undue crowding, a safety car 65, and a 30-passenger bus not over 45, if the buses are to be kept within the weight and price limits specified. A comparison based on a car-for-

TABLE III

OPERATING COSTS OF GASOLINE BUSES IN CENTS PER BUS MILE

Line 1.	Chicago Motor Bus Co	1919	10,000-lb. bus, solid tires
Line 2.	Fifth Ave. Coach Co	1920	10,000-lb. bus, solid tire
Line 3.	Baltimore Transit Co	1920	7,500-lb. bus, solid tires
Line 4.	Fort Worth Auto Bus Co	1919	5,700-lb. bus, pneumatic front tires, solid rear tires
Line 5.	Goodyear Heights Bus Line	1920	8,000-lb. bus, pneumatic tires

Maintenance	1	2	3	4	5	Average
MAINTENANCE:						
Tire renewals	2.1	1.0	1.5	1.4	5.6	2.9
Body repairs	0.9	0.6	1.4	0.9	0.9	0.9
Engine, gearing and control	5.7	4.0	4.8	3.3	3.3	4.3
Shop and other expenses	1.9	1.2	1.6	1.0	1.0	1.3
Total maintenance	10.6	6.8	9.3	9.6	10.8	9.4
Gasoline	4.0	5.3	7.1	2.7	4.9	4.8
Lubricant	0.8	1.2	1.5	0.9	1.5	1.2
	4.8	6.5	8.6	3.6	6.4	6.0
All other operating expenses	17.3	19.8	15.9	12.2	10.6	15.2
Total operating costs	32.7	33.1	33.8	25.4	27.8	30.6
Depreciation	3.2	2.4	6.7	9.1	4.9	5.3
Total maintenance with solid tires costs on Lines 4 and 5	10.6	6.8	9.3	7.7	7.5	8.4
Gasoline and oil corrected for 10,000 lb. wt. on Lines 3, 4 and 5	4.8	6.5	10.8	5.6	7.7	7.1
Other expenses corrected for one-man operation, Lines 1 and 2	12.2	12.3	15.9	12.2	10.6	12.6
Total operating cost of 10,000-lb. bus with solid tires and one-man operation	27.6	25.6	36.0	25.5	25.8	28.1

TABLE IV

FIXED CHARGES ON TOTAL INVESTMENT

	Rail System Per Cent	Trolley Bus Per Cent	Gasoline Bus Per Cent
Interest charges	9.0	9.0	9.0
Taxes and insurance	2.8	2.8	2.8
Depreciation	3.2	3.7	6.9
Total	15.0	15.5	18.7

car replacement is obviously unfair, except where the maximum number of people to be carried is within the seating capacity of either type of vehicle.

A number of comparisons have been worked out, based on differing density of traffic from very light to extremely heavy, each based on a completely equipped line four to five miles long, and all costs reduced to the unit basis of one route-mile.

With these prefatory statements, the tables are believed to be self-explanatory. They indicate clearly that the railway is still the most economical means of handling very dense traffic, and that for very short headways there is little to choose in first cost or operating charges between a comparatively small number of large capacity double-truck rail cars of modern design and the larger number of safety cars required, as shown in Table IX. To handle such traffic as this, headways with the comparatively small capacity buses become so short as to be prohibitive, and their higher operating costs far overbalance their saving in fixed charges.

TABLE V

COST PER ROUTE-MILE, LIGHT TRAFFIC, CITY SERVICE, FOR BUILDING AND EQUIPPING RAILWAY SYSTEM, AND FOR PROVIDING EQUIVALENT PASSENGER CAPACITY WITH GASOLINE AND WITH TROLLEY BUSES

	Safety Car	Trolley Bus	Gasoline Bus
Schedule speed, m.p.h.	9	10	10
Normal headway (13 hr. daily) minutes	15	15	15
Rush-hour headway (5 hr. daily) minutes	10	6.7	6.7
Seats furnished per hour, normal headway	128	120	120
Maximum rush-hour capacity	390	405	405
Cars required, including spares	1.56	2.0	2.2
Annual car-miles or bus-miles	58,500	68,200	68,200
Cost of Road Equipment:			
Single track	$60,000	....	....
Overhead system, trolley and transmission	6,700	$ 6,900	....
Power station and substation	6,000	7,600	....
Shops or garages	2,300	3,000	$ 3,300
Cars or buses	9,800	16,000	17,600
Total investment	$84,800	$33,500	$20,900
Fixed charges at 15, 15.5 and 18.7 per cent	$12,700	$ 5,200	$ 3,900
Operating costs at 18.2, 19 and 27.5 cents	10,600	13,000	18,800
Total costs per year	$23,300	$18,200	$22,700
Costs per car-mile, cents	40	26.7	33.3

ON BASIS OF TRACK AND STRUCTURES COSTING 50 PER CENT OF ABOVE

	Safety Car	Trolley Bus	Gasoline Bus
Total investment	$47,300	$24,800	$19,300
Fixed charges	7,100	3,800	3,600
Operating costs	10,600	13,000	18,800
Total costs per year	$17,700	$16,800	$22,400
Cents per car-mile	30.3	24.6	32.8

	TABLE VI MEDIUM TRAFFIC ROUTE			TABLE VII MODERATELY HEAVY TRAFFIC ROUTE		
	Safety Car	Trolley Bus	Gasoline Bus	Safety Car	Trolley Bus	Gasoline Bus
Schedule speed, m.p.h.	9	10	10	9	10	10
Normal headway (13 hr. daily) minutes	10	10	10	7.5	7.5	7.5
Rush-hour headway (5 hr. daily) minutes)	7.5	5	5	4	2.7	2.7
Seats provided per hour, normal	192	180	180	256	240	240
Maximum rush-hour capacity	520	540	540	975	990	990
Cars required, including spares	2	3.1	3.33	3.8	5	5.4
Annual car-miles or bus-miles	84,800	97,600	97,600	127,000	148,800	148,800
COST OF ROAD AND EQUIPMENT:						
Track	$75,000			$100,000		
Overhead system, trolley and transmission	6,800	$ 6,900		7,000	$ 7,400	
Power station and substations	8,000	10,100		14,400	17,600	
Shops or garages	3,000	4,200	$ 4,500	5,600	7,500	$ 8,100
Cars or buses	12,600	22,400	24,000	23,800	40,000	43,200
Total investment	$105,400	$43,600	$28,500	$150,800	$72,500	$51,300
Fixed charges per year	$ 15,800	$ 6,800	$ 5,300	$22,000	$11,200	$ 9,600
Operating costs per year	15,400	18,500	26,800	23,100	28,300	41,100
Total costs per year	$31,200	$25,300	$32,100	$45,700	$39,500	$50,700
Cents per car-mile	36.7	25.8	32.8	36	26.5	34.0

ON BASIS OF TRACK AND STRUCTURES COSTING 50 PER CENT OF ABOVE

	Safety Car	Trolley Bus	Gasoline Bus	Safety Car	Trolley Bus	Gasoline Bus
Total investment	$58,900	$33,000	$26,300	$87,300	$56,300	$47,300
Fixed charges	8,800	5,100	4,900	13,100	8,700	8,800
Operating costs	15,400	18,500	26,800	23,100	28,300	41,100
Total costs per year	$24,200	$23,600	$31,700	$36,200	$37,000	$49,900
Cents per car-mile	28.5	24.3	32.4	28.6	24.8	33.5

TABLE VIII — HEAVY TRAFFIC ROUTE / TABLE IX — VERY HEAVY TRAFFIC ROUTE

	Safety Car	Trolley Bus	Gasoline Bus	‡ Double-truck Car	Safety Car	Trolley Bus	Gasoline Bus
Schedule speed, m.p.h.	9	10	10	8.5	8.5	9.5	9.5
Normal headway (13 hr. daily) minutes	5	4.6	4.6	4	2.4	2.15	2.15
Rush-hour headway (5 hr. daily) minutes	3	2.1	2.1	2	1.1	0.75	0.75
Seats per hour, normal	348	390	390	780	800	840	840
Maximum rush-hour capacity	1,300	1,300	1,300	3,600	3,580	3,600	3,600
Cars required, including spares	5.1	6.6	7	8	14.6	19.4	20.2
Annual car-miles	182,000	220,600	220,600	243,000	423,000	530,000	530,000
COST OF ROAD AND EQUIPMENT:							
Double track	$100,000			$120,000	$110,000		
Overhead system	7,500	$ 7,900		7,500	7,500	$ 8,000	
Power station and substations	19,300	23,200		64,100	53,900	67,800	
Shops or garages	7,700	9,900	$10,500	20,000	21,900	29,100	$30,300
Cars or buses	32,200	52,800	56,000	95,900	91,500	154,700	161,700
Total investment	$166,700	$93,800	$66,500	$307,500	$284,800	$259,600	$192,000
Fixed charges per year	$25,000	$14,500	$12,400	$46,200	$42,700	$40,200	$35,900
Operating costs	33,000	42,100	60,800	76,100*	77,000	100,800	146,000
Total cost per year	$58,000	$56,600	$73,200	$122,300	$119,700	$141,000	$181,900
Cents per car-mile	31.8	25.5	33.1	50.5	28.2	26.6	34.2

ON BASIS OF TRACK AND STRUCTURES COSTING 50 PER CENT OF ABOVE

	Safety Car	Trolley Bus	Gasoline Bus	Double-truck Car	Safety Car	Trolley Bus	Gasoline Bus
Total investment	$99,500	$73,300	$61,200	$202,000	$198,000	$217,000	$177,000
Fixed charges	14,900	11,400	11,400	$30,400	$29,700	$33,600	$33,100
Operating costs	33,000	42,100	60,800	76,100*	76,900	100,800	146,000
Total costs per year	$47,900	$53,500	$72,200	$106,500	$106,600	$134,400	$179,100
Cents per car-mile	26.3	23.7	32.7	43.8	25.2	25.4	33.7

* With one-man operation, the large car costs would be reduced $17,000 a year.

‡ Modern car seating 52, maximum load capacity 120, weight 36,000 lb.

	TABLE X LIGHT TRAFFIC			TABLE XI VERY LIGHT TRAFFIC		
	Safety Car	Trolley Bus	Gasoline Bus	Safety Car	Trolley Bus	Gasoline Bus
Schedule speed, m.p.h.	10	10	10	10	10	10
All-day headway minutes	20	20	20	30	30	30
Seats per hour, normal	96	90	90	64	60	60
Maximum capacity	195	135	135	130	90	90
Cars required, including spares	0.75	0.75	0.75	0.5	0.5	0.5
Annual car-miles	39,300	39,300	39,300	26,300	26,300	26,300
COST OF ROAD AND EQUIPMENT:						
Single track	$55,000			$55,000		
Overhead system	6,700	$ 6,900		6,700	$6,900	
Power station and substations	3,000	2,500		2,000	1,700	
Shops or garages	1,100	1,100	$ 1,100	800	800	$800
Cars or buses	4,700	6,000	6,000	3,100	4,000	4,000
Total investment	$70,500	$16,500	$ 7,100	$67,600	$13,400	$4,800
Fixed charges	$10,600	$2,150	$ 1,320	$10,100	$2,100	$ 900
Operating costs	7,150	7,450	10,810	4,800	5,000	7,230
Total costs per year	$17,750	$9,600	$12,130	$14,900	$7,100	$8,130
Cents per car-mile	45	24.5	30.8	56.8	27	30.9

ON BASIS OF TRACK AND STRUCTURES COSTING 50 PER CENT OF ABOVE

	Safety Car	Trolley Bus	Gasoline Bus	Safety Car	Trolley Bus	Gasoline Bus
Total investment	$37,600	$11,250	$6,550	$35,100	$8,700	$4,400
Fixed charges	$5,650	$1,750	$1,210	$5,300	$1,300	$800
Operating cost	7,150	7,450	10,810	4,800	5,000	7,230
Total costs per year	$12,800	$9,200	$12,020	$10,100	$6,300	$8,030
Cents per car-mile	32.5	23.4	30.5	38.4	24	30.5

But for many other conditions, particularly those which are typical of the majority of lines in medium size cities, where the maximum traffic does not require headways of less than five or six minutes, the trolley bus should save enough in overhead charges to justify its use in preference to either the rail car or the gasoline bus.

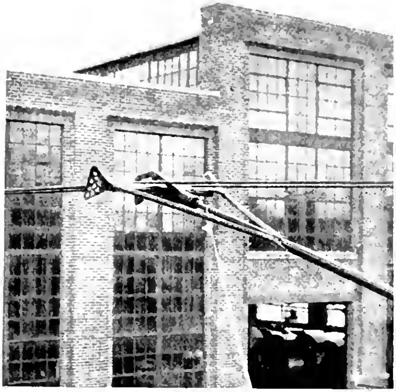


Fig. 10. Collector Head for Trackless Trolley Equipment

For instance, in the figures of Table V a very common situation is pictured, i.e., a line on which an all-day headway of 15 minutes with a medium size rail car is sufficient but on which the morning and evening loads require a 10-minute headway. We assume that safety cars would be used on the rail route and that they would maintain a schedule of nine miles per hour. If buses were used, presumably they could run somewhat faster due to their ability to run past slower moving vehicles, and because of their smaller load in rush hours. The figures are based on a 4.5-mile route on which the safety cars required 60 minutes for the round trip and the buses 54 minutes. Even so, to carry away an equal number of passengers during the rush hours will require eight buses on a 6.75-minute headway as against six safety cars, 10 minutes apart. One spare car is allowed in the case of the safety car line and for the trolley bus route, and two spares if gasoline buses are used, because of the greater chance of failure with the gasoline engine.

Power requirements are based on the rail cars taking, at the car, 150 watt-hours per ton-mile, and the trolley bus taking 195 watt-hours per ton-mile, for all energy required except heat. These figures are increased 15 per cent for line losses and 25 per cent more for conversion. On either vehicle, heaters are assumed to take a continuous maximum input of 12 amp.

Of the total investment required for a new rail line, under these conditions, 60 per cent is saved by using the trolley bus and 75 per cent by equipping with gas buses, and the saving is very material even against the company using old rail and structures. The fixed charges are therefore distinctly lower for bus systems, but the gasoline buses cost so much more to operate that the total annual cost of the line using them is practically the same as for the new railroad, and 30 per cent higher than for the existing rail system.

The operating cost of the trolley bus, however, is so little more than that of the rail car that it does not offset the savings in the fixed charges, and its total cost of service is the lowest of the three systems.

Another common traffic condition is shown in Table VI; a route that would be satisfactorily handled with safety cars on 10-minute normal and 7.5-minute rush-hour headways, and where buses would have to run on a 5-minute spacing to give equivalent rush-hour capacity.

Here again the use of the trolley bus is the cheapest way to equip a new line or to extend an old one; the gasoline bus the most expensive means.

As the traffic grows more heavy, as in Table VII, the advantage of the trolley bus over the rail car diminishes, but its advantage over the gasoline bus continues in the same proportion as before. The figures indicate that to re-equip an existing line would show a total loss rather than gain by abandoning rail operation.

With headways as short as shown in Table VIII, rail operation is practically as cheap as trolley bus service, even in the case of new construction; on the old rail, operation is decidedly more economical.

In Table IX we show a very heavy traffic route, which could use large modern double-truck cars, for instance the Peter Witt type, on four-minute and two-minute headways. It might be practicable to use safety cars on such a route, though the rush-hour headways would be rather short, but no real advantage would be gained, their total cost of service being practically equal to that of the large cars. Many persons are coming to believe that Witt cars can be one-man-operated, and as such they would show by far the lowest cost of any vehicle that could be employed.

The enormous number of buses that would be required for this kind of traffic, necessitating headways of 45 seconds, throws them out of the competition. Their use would not only tremendously increase street congestion, but would very considerably increase the cost of service.

The only place where the gasoline bus can successfully compete with the rail system is where traffic is so light that bus headways of 20 minutes or longer afford sufficient service. In tabulations X and XI trolley and gasoline buses on 20- and 30-minute all-day headways are compared with a safety car installation operating at the same speed and frequency. With 20-minute service, the old rail-route about balances in total cost with the gasoline bus line; at today's construction expense, the gasoline bus is distinctly cheaper. At 30-minutes, the advantage is decidedly in favor of the gasoline car. But at either headway, the trolley bus will have the lowest total cost of the three, and calculations indicate that its advantage over the gasoline vehicle holds up to headways of one hour or longer.

In conclusion, we believe that there is still a broad field of transportation on city streets for which the rail car is best suited and in which it is the most economical means of carrying passengers, but there is another, and perhaps equally important field, in which the trolley bus can furnish equivalent service at a lower cost than can the rail system. Even in comparison with the rail system, the field for the gasoline bus is very limited, (on headways of 20 minutes or longer) while as compared with the trolley bus it has no place in a city transportation system, except where it is impossible to erect an overhead trolley line.

The trolley bus, however, furnishes an important contribution to the art of transportation, because its possibilities enable transportation companies to extend their lines into the suburbs or into new sections of a city, with an investment 60 to 80 per cent less than is required for a track system, and to be able to operate cars over the new route for two-thirds of the cost of gasoline buses. With these trackless electric vehicles, it should be possible very considerably to extend the services of the city transportation companies and to benefit simultaneously the traveling public and the electric railway security holder.

Peter Witt Type of Rail Car, Suitable for Heavy Traffic Routes

Control Equipments for Steel Mill Auxiliary Motors*

By J. D. Wright

Power and Mining Engineering Department, General Electric Company

The present standard control equipment for automatically accelerating steel mill auxiliary motors employs the principle of current limit control, involving the use of shunt contactors and current limit relays. The relay coil is connected in series with the motor and consequently coils of various capacities are required in order to adapt this system to motors of various sizes. Further objections to this method are sometimes encountered, such as the difficulty of obtaining sufficiently low calibration where the machine is over motored, and in certain forms the necessity of mechanical connection between contactor and relay is troublesome. This article describes a system of control in which a single self-contained relay may be used for all sizes of motors and in which only one size of relay coil is required for a given voltage. The equipment functions on a truly current limit principle; but instead of the line current passing through the relay coils the relays are excited by the voltage drop across the starting resistor, which of course is proportional to the line current. This change results in a marked simplification of equipment and thoroughly satisfactory operation.—Editor.

Steel mill auxiliary motors driving mill tables, screw downs, side guards, etc., are subjected to the severest service to be found in any application of electric drive. Furthermore, uninterrupted operation is of extreme importance, since delays, even if slight, become costly.

In developing the control for these auxiliary motors, close cooperation has existed between the steel mill electrical engineer and the manufacturer and rapid progress has resulted. Special effort by the manufacturer to obtain complete knowledge of the operating conditions has enabled him to design simple and sturdy apparatus which will function properly in this severe service. Careful study has been made of control equipments in service which has suggested modifications here and there and resulted in the elimination of those features which were the cause of occasional trouble; simplicity is highly desirable, and this qualification has been carried to the extreme.

The earliest applications of control for steel mill auxiliary motors showed at once that some means of automatic acceleration was desirable in order to reduce the excessive cost of repairs on electrical and mechanical equipment, occasioned by the improper use of manually operated controllers.

Many schemes were tried, such as time limit control (generally obtained by the use of some form of dashpot), counter e.m.f. starters, and finally current limit control in which proper acceleration of the motor is obtained by allowing the contactors which cut out the starting resistor to close only when the accelerating current has fallen to the desired value. At the present time the standard method is current limit control, obtained by the use of shunt contactors and current limit relays, or by the use of series contactors. However, because of the limitations of the series contactor, the more widely used system is that having shunt contactors and current limit relays. A satisfactory system extensively applied today uses a

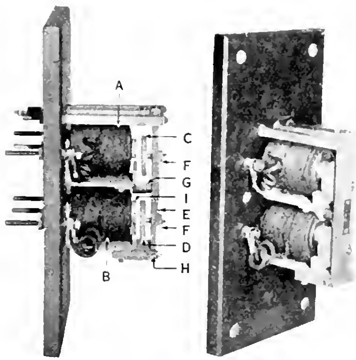


Fig. 1. Voltage-drop Relay

current limit relay, held open mechanically by the contactor with which it is used. This relay naturally drops by gravity when its contactor closes but may be held up magnetically if sufficient current is passing through the relay coil. This coil is connected in series with the motor and therefore must have a current capacity corresponding with the size of motor with which it is used. As a result, coils of several different capacities must be available in order to adapt this system to various sizes of motors. Difficulty might be experienced in getting a sufficiently low calibration where the drive is over-motored. Furthermore, the necessity of mechanical

*Rewritten for the General Electric Review from a paper presented at the Chicago section of the Association of Iron and Steel Electrical Engineers.

connection between contactor and relay has in some cases, been objectionable.

It is evident that if a system were devised whereby a single self-contained relay could be used for all sizes of motors, and if for a given line voltage only one size of relay coil were necessary, a great simplification in the control would be effected. This paper describes such a system, in which the starting of the motor is controlled by current limit relays, actuated not directly by the current flowing in the circuit but by the voltage across the starting resistor. This voltage is proportional to the current flowing in the resistor and the relay therefore functions on a truly current limit scheme.

The type of relay used has been called a voltage-drop relay and is illustrated in Fig. 1. It has two independent magnetic circuits with an upper calibrating coil A and a lower assisting coil B. The air gap adjusting nuts, C and D, are fastened to studs which screw into the armature E and are held by lock nuts F. The compression spring G holds the relay contacts normally closed. In order to remove a coil the pin H is taken out, thereby allowing the armature E to drop. The core I, which fastens the coil to the frame, may then be unscrewed.

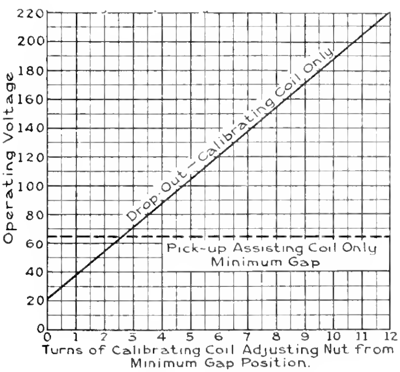


Fig. 2. Range of Calibration of Voltage-drop Relay on 250-volt Circuit

Both coils of the relay are energized to pick up the armature, thereby opening the relay contacts. However, after being picked up the assisting coil is short circuited by a contactor as described later, so that the voltage at which the armature will release and close the contacts may be varied by the upper adjusting nut C.

Fig. 2 shows the calibration curve for a voltage-drop relay designed for operation on a 250-volt direct current circuit. The armature will be picked up by the assisting coil, acting

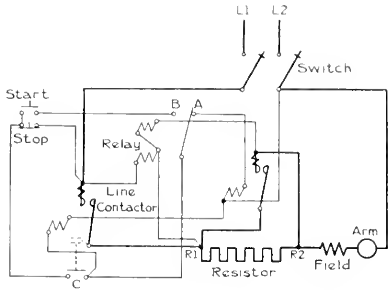
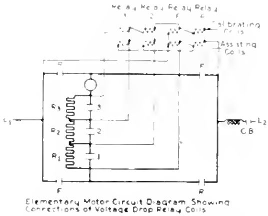


Fig. 3. Non-reversing Starter with Voltage-drop Relay

alone, at approximately 65 volts, and the drop out with only the calibrating coil energized may be varied from approximately 20 volts to 220 volts by turning the calibrating coil adjusting nut so as to increase the upper air gap.

A typical scheme of connections for a single point non-reversing starter is shown in Fig. 3. As soon as the line switch is closed the calibrating and assisting coils of the relay are connected in series across the line and the armature is picked up. This causes the contact at A to be opened and the contact at B to be closed. When the starting push button is closed, current flows from L-1 through the stop push button, through the start push button, through contact B and through the coil of the line contactor to the other side of the line. This closes the line contactor, and its interlock C establishes a holding circuit through the stop push button. The closing of the line contactor short circuits the relay assisting coil and leaves the calibrating coil connected across the starting resistor so that the voltage on the calibrating coil is proportional to the current flowing through the resistor. When the motor is started from rest this voltage is practically equal to full line voltage, but as the motor accelerates its counter e.m.f. increases, thereby reducing the current from the line and the voltage on the coil. At a predetermined voltage the relay armature releases, closing contact A, which causes the accelerating contactor to close and short circuit the starting resistor.

Fig. 4 has been prepared to show the connections of the relay coils on a typical reversing steel mill control panel and the voltage



Relays		Control Points								
		Reverse				Off	Forward			
		4	3	2	1		1	2	3	4
F	Calibrating Coil	100	100	100	$100-IR_1$	50	IR_1	0	0	0
	Assisting Coil	100	100	100	100	50	0	0	0	0
R	Calibrating Coil	0	0	0	IR_1	50	$100-IR_1$	100	100	100
	Assisting Coil	0	0	0	0	50	100	100	100	100
2	Calibrating Coil	0	0	IR_2	IR_2	0	IR_2	IR_2	0	0
	Assisting Coil	0	0	0	IR_1	0	IR_1	0	0	0
3	Calibrating Coil	0	IR_3	IR_3	IR_3	0	IR_3	IR_3	IR_3	0
	Assisting Coil	0	0	IR_2	IR_1+IR_2	0	IR_1+IR_2	IR_2	0	0

Table Showing Per Cent Voltage Applied to Operating Coils of Voltage Drop Relays on Various Control Points

Fig. 4. Voltage Applied to Voltage-drop Relay Coils on Various Control Points of a Reversing Panel

applied to these coils on the various control points.

Four relays are used, two of which control the closing of contactor 1, which short circuits the plugging resistor. Relay F controls the closing of contactor 1 when contactors F close, and relay R controls the closing of contactor 1 when contactors R close. Relay 2 controls the closing of contactor 2 and relay 3 the closing of contactor 3.

The connections from the master controller through the relay contacts to the reversing and accelerating contactors have been omitted in order to simplify the diagram. With the controller in the off position, all contactors are open except the circuit breaker contactor CB. On this point the calibrating coils and the assisting coils of the relays F and R are in series across the line. As a result, both relay armatures are picked up and the contacts opened in readiness for action when the forward or reverse contactors are closed. If the controller is thrown to the forward position, the contactors F close and voltage conditions on the relay coils are as shown in column 1 under "Forward." The lower left hand contactor F short circuits the assisting coil on relay F and connects the calibrating coil across the first section of the resistor R-1, so that the voltage applied to this coil is equal to the IR drop across the resistance. This drop decreases as the motor accelerates, until at a predetermined value the relay F armature releases and closes contactor 1. However, as soon as contactors F close, the armatures of relays 2 and 3 are picked up by the voltage drop across R-1, R-2 and R-3 as indicated, so that these relays are ready to function when required. The closing of contactor 1 short circuits the assisting coil of relay 2. When the voltage across R-2 decreases to the setting of relay 2, its armature will release and close contactor 2, which in turn short circuits the second section of the resistor R-2 and also the assisting coil on relay 3. In the same way the armature of relay 3 is released when the voltage drop across R-3 has decreased to the relay setting, and contactor 3 is closed.

It will be seen that on all points "Forward" the relay R remains open with full voltage on the assisting coil. On all points "reverse" the relay F remains open and the closing of contactor 1 is controlled by the relay R. Relays 2 and 3 function for reverse operation in the same manner as for forward operation.

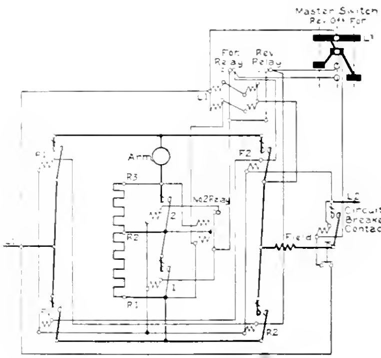


Fig. 5. Reversing Controller with Voltage-drop Relays

Fig. 5 is a diagram showing all connections for a reversing equipment with two contactors for cutting out the starting resistor.

The voltage-drop relay possesses a rather interesting characteristic which can be effectively utilized on control equipments for motors which operate under variable load conditions. This is a small time lag in the releasing of the relay armature which occurs after the assisting coil is short circuited. This lag is caused by the relatively slow decrease in flux due to the self induction of the short

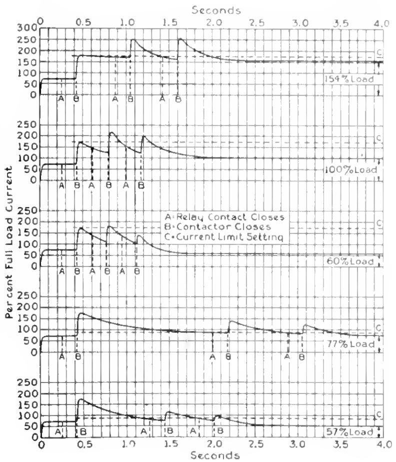


Fig. 6. Accelerating Curves of Series Motor with Acceleration Control by Voltage-drop Relays

circuited coil. This lag may be varied from approximately 0.05 seconds to 0.3 seconds by changing the position of the assisting coil air gap adjusting nut. Change in this gap of course does not affect the calibration of the relay as fixed by the position of the calibrating coil air gap adjusting nut.

Advantage can be taken of this time lag by calibrating the relays to close the accelerating contactors at a relatively high value of current, for example, at a current to give twice normal torque. This would allow acceleration of the motor when heavily loaded, but when lightly loaded the time lag would produce an effect equivalent to a lowered current limit setting. That this time lag, small though it may be, is effective in reducing the current peaks when the motor is accelerating a light load is evident from the curves shown in Fig. 6 which have been plotted from oscillograph records. The tests were made on a 70-h.p. 230-volt series mill type motor.

In each of the curves the full lines represent the current input to the motor, the horizontal dotted line the current value at which the relay armature releases, A the point at which the relay closes its contactor coil circuit, and B the point at which the contactor closes and short circuits a block of resistance.

The first curve shows the current input when starting with a load torque of approximately 180 per cent of normal torque (154 per cent current) and with a current limit setting of 173 per cent of normal current. The maximum accelerating peak is 268 per cent and the time required to put the motor

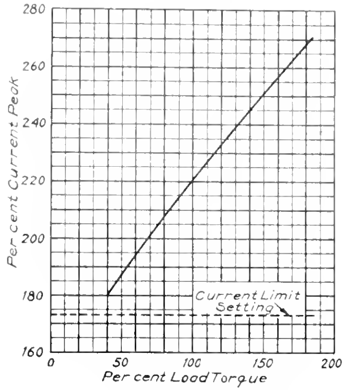


Fig. 7. Curve Showing Decrease of Current Peaks on Light Loads Plotted from Curves in Fig. 6

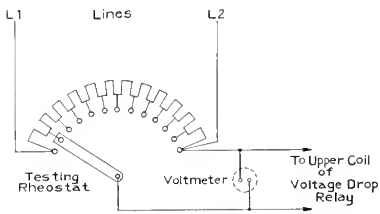


Fig. 8. Method of Calibrating Voltage-drop Relays

armature directly across the line is 1.6 seconds.

The second curve shows the current when accelerating against full load torque (100 per cent current) with the same current limit setting as in the first curve. The maximum accelerating peak is 220 per cent and the time required to put the motor armature directly across the line is 1.17 seconds. It will be noted that the current values at which the last two contactors closed are materially lower than in the first curve. This has occurred as a result of the time lag in the operation of the relays and contactors.

The third curve shows the current when accelerating against approximately 40 per cent full load torque (60 per cent current) with the same high current limit setting. Here again the closing of the contactors was limited only by their own time lag and that of the relays, but the maximum peak is reduced to approximately 180 per cent. The time required to put the motor armature directly across the line is 1.12 seconds.

The last two curves show acceleration with the current limit setting of the relays reduced to approximately 90 per cent full load current and accelerating against load torques of 77 per cent and 57 per cent. In both of these curves the acceleration was entirely current limit and not time limit as in the second and third curves.

The curve in Fig. 7 has been plotted to show the maximum accelerating peaks for various loads with a fixed current limit setting and illustrates clearly the decrease in current peak with decrease in load.

The calibration of the relays is very readily accomplished by means of a small adjustable rheostat and voltmeter, as shown in Fig. 8. No large current is required for calibration and a set of relays can be adjusted before being put in stock. They can be used with any size of motor which uses the same number of accelerating contactors. Only one type of relay and only one size of coil is required for all sizes of motors designed for the same voltage.

The relays may be grouped together on a control panel as shown in Fig. 9 and readily protected from dust and dirt by an enclosing cover which may be locked, thus preventing changes in the adjustment of the relays by unauthorized persons.

This scheme of control also provides a means for the elimination of electrical inter-

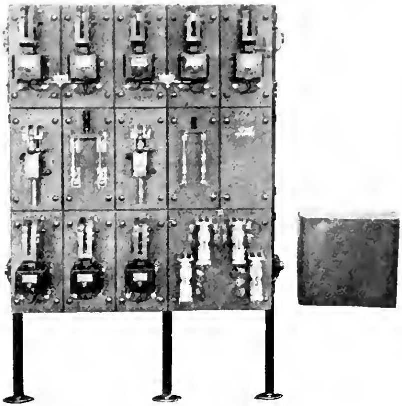


Fig. 9. Standard Reversing Control Panel with Voltage-drop Relays Mounted on Lower Right Section

locks. The only interlock used is that on the circuit breaker contactor, this one being necessary to provide under-voltage protection.

An increase in the resistance of the starting resistor, due to heating, tends to decrease the corresponding motor current value at which the relay drops out. An increase in the resistance of the relay shunt coil, due to heating, tends to increase the corresponding motor current value at which the relay drops out. These two factors approximately neutralize each other so that the drop out of the relay occurs at approximately the same value under operating conditions.

The Electrification of Merchant Ships

By E. D. Dickinson

Marine Engineering Department, General Electric Company

"The Electrification of Merchant Ships" is a problem of today as "The Electrification of Mills" and "The Electrification of Railways" were problems but a few years ago. History is likely to repeat itself and the most easily and the most economically controlled form of energy is likely to assume its rightful place on board ship as it has in mills and on railroads to the lasting benefit of mankind. The present article forms the first of a number that we hope to publish in the near future under the general title of "The Electrification of Merchant Ships."—Editor.

Undoubtedly, some day a comprehensive book will be written describing in sufficient detail the application of electricity to all ships. Since there are many special considerations affecting its use on fighting ships, electricity on merchant ships should, therefore, be considered apart from its application to naval vessels. At this particular time, when much thought is being given to the future of our Merchant Marine, it would seem most suitable that we should discuss the application of electricity to our vessels engaged in mercantile transportation.

There is little question but that we are all looking forward to a re-establishment of our Merchant Marine, and from time to time we hear discussions as to just what should be done in its interests. There is a great diversity of opinion, and in order that we may intelligently consider all phases of the subject, it is essential that we familiarize ourselves with existing conditions.

Mercantile shipping is probably the most highly competitive business in the world. Goods are transported between ports on the seven seas, and naturally the owners of these goods will avail themselves of the least expensive means of having them carried. In a few cases sentiment may play a part, but no serious consideration should be given to this factor. The Glasgow (Scotland) *Herald* of December 30, 1920, published an interesting article by W. J. Noble, President of the Chamber of Shipping, which reads in part as follows:

"As the seas are free to everyone, so British ports are free to everyone. The same port charges, no more and no less, are levied on foreign vessels and on British vessels; the state does not even reserve the trade around our coast to ships under the British flag, but offers to all shipping absolute equality of treatment. No industry is consequently confronted with keener competition than the shipping industry, with the result that this island country, far from being at the mercy of the British ship owner, always obtains the lowest world price for the carriage of its imports and exports."

It is difficult to see how laws can be made which will be of any material benefit to ships in a foreign trade. Any particular advantages that may be granted to ships under our flag can be, and most likely will be, nullified by similar advantages granted by other countries to their own ship owners. There seems to be a common belief that many foreign ships are highly subsidized. This is not quite true. The writer would call attention to a paragraph appearing on page 51 of a pamphlet issued in 1916 by the Department of Commerce in Washington and prepared by Grosvenor M. Jones, reading as follows:

"At no time in its history has Great Britain paid a general bounty on the construction or operation of merchant ships. Its financial aid has been limited to the payment of fixed amounts for the regular transportation of British and colonial mails on specified routes by companies with which special contracts have been made. No general bounties have been given, as in France, Italy, Austria and Spain, for all vessels built in domestic yards or for all vessels operated under the national flag. In fact, the direct financial aid extended by the British Government has at no time reached more than 5 per cent of the total tonnage under the British flag, and has not benefited the hundreds of cargo ships which have been the main source of strength of the British Merchant Marine and the chief reliance of British industry and trade."

You may perhaps ask what has all this to do with electricity on merchant ships? It has everything to do with it, and we must realize that the question is entirely an economic one—economic in its broadest interpretation.

It is not sufficient to show that there will be a reduction in the amount of fuel required, but all the other factors affecting operation must be given proper consideration. In other words, a ship electrically equipped must show a better return for the money invested than one fitted with steam machinery.

To decide on the most suitable equipment, proper consideration must be given to all factors entering into operation and a detailed comparison made between the types of equipment which are being considered. The time for hasty decisions is past, and from now on there will be no excuse for owners installing equipment without having made a thorough investigation.

In engineering it is risky to deal in generalities. In nothing is this so exemplified as in the diversified engineering problems presented in the study of the economical operation of merchant ships. It was recognized years ago, though fuel was relatively inexpensive, that for certain classes of trade highly efficient machinery would be warranted, whereas for short trips the least expensive reliable machinery would prove most economical in the yearly operation of a ship. The problem has been intensified by changed conditions, fuel and other items having been increased in cost, available cargoes having been decreased, and more ships waiting for the trade that is offered; in other words, competition is keener and operating costs higher. Therefore, as is natural in all commercial enterprises, greater care must be taken to eliminate all avoidable costs in operation. For this reason, engineers interested in our Merchant Marine will be expected to study the problem from all angles and be familiar with the various details entering into the operating cost of ships to a far greater extent than has been the case heretofore.

Operating Expenses

The costs of operating merchant ships are commonly classified as Capital Charges and Operating Expenses. Capital Charges consist of interest on the investment, depreciation, and very often insurance on the hull.

Operating Expenses consist of:

1. Port charges, including wharfage, stevedoring, lighterage, port fees, canal dues, and tug boat charges
2. Fuel and lubricating oil
3. Salaries and subsistence
4. Upkeep—deck department
5. Upkeep—engine department
6. Supplies
7. Insurance on cargo
8. Loss and damage.

To give an idea of the cost of operating a 7800 dwt. ship, an article recently published in the *Daily Marine Record* and also in the daily press, gave a figure of $500 per day which included interest, depreciation, insurance, repairs, wages, subsistence, stores, etc., but did not include fuel. In this figure, insurance is based on the high value of $175 per dwt. ton placed on the vessel by the Shipping Board. The total may be divided approximately as follows:

Interest	$64 per day
Insurance	90 per day
Depreciation and obsolescence	52 per day
Maintenance and repairs	60 per day
Wages and subsistence	160 per day
Stores	54 per day
Loss and damage	20 per day

To this must be added port charges. These vary greatly and will depend on the ports of call, number of trips per year, seasons of the year, terminal facilities, and many other factors.

Taking the case of a 7800 dwt. ship, valued at $50 per dwt., making 3 round trips of about 12,000 miles per trip per year at an average speed of 9.5 knots, the total expenses, say between the East and West Coasts, would be approximately as follows:

Fixed charges	
Interest	$64 per day
Insurance	44 per day
Depreciation and obsolescence	52 per day
Total fixed charges	$160 per day
Operating expenses	
Port charges	$410 per day
Fuel, water, and lubricating oil	200 per day
Wages and subsistence	160 per day
Maintenance and repairs	60 per day
Stores	54 per day
Loss and damage	20 per day
Total operating expenses	$904 per day
Total	$1064 per day

In this estimate, the ship would be at sea for 162 days in the year, or for 44 per cent of the time, making a yearly total of 36,000 miles, which agrees with the records of a large number of cargo vessels in service.

It will be evident that any means which will reduce the time taken for loading and unloading, so as to keep the ship at sea for a greater portion of time, will add greatly to the earning power of the ship. Port charges which in this case approach 40 per cent of the total charge vary with the time in port. An extra trip, or part of a trip, may change a loss to a net profit.

A great deal has been written, and much time has been given to the discussion of electric ship propulsion. At first glance it would appear that the initial cost would be greater and the efficiency lower without any compensating advantages. Studies of specific cases show that this is not always a fact. It is impossible to make a general statement as to the most suitable drive for ships. Each case should receive special consideration.

It is not difficult to show the gains that can be obtained by the general adoption of electricity to drive all auxiliary machinery. By auxiliaries is meant all machinery on a ship other than the main propulsion turbine or engine. Numerous articles indicate to what extent suitable marine electrical equipment has been developed. An article in the *Electrician* (London) of September, 1920, states as follows:

"It may be added that as is now becoming universally the case in this country, all the auxiliary machinery is operated electrically."

The advent of the motor ship has had much to do with the development of suitable electric auxiliary equipment. Much of the gain made possible by the use of the oil engine would be sacrificed if it were necessary to install steam boilers, steam piping, fittings, and steam auxiliary machinery. We see an ever increasing number of foreign ships fitted with electric auxiliary machinery. Much of it shows a high degree of development. Reports are to the effect that it has definitely replaced steam for the best new ships. What has developed abroad will ultimately take place in this country. Manufacturers of deck and engine room machinery in this country have done a great deal of developmental work and are in a position to furnish electrically operated apparatus as good, if not better, than that being built abroad.

In estimating the gain that may be obtained by installing auxiliaries driven by electricity instead of steam, we must recognize conditions as they really exist. A comparison based on tests only between a steam and an electrically driven auxiliary is misleading. We know from experience that the steam equipment on a ship after it has been in service for a relatively short time uses 25 to 30 per cent of the total steam consumed; for example, it was recently reported that on a freighter equipped with 2500-h.p. turbine and three boilers, one boiler could not supply sufficient steam to operate the auxiliaries while in port. A reported test of a British ship showed the steam consumption of the auxiliaries in operation during the voyage to be 30 per cent of the total steam consumption.

TURBINE-ELECTRIC PROPULSION

In the history of electric ship propulsion there have been conspicuous cases of success as well as a few cases of failures. This is but natural in the development of any art. Mistakes in design, troubles resulting from the installation of improperly manufactured or unsuitable machinery must be expected, and a certain amount of criticism, sometimes unfair, is the result. Before drawing conclusions, it is essential that we study all available data and learn the reasons why some installations failed while others operated so successfully.

We are informed that the British Ship, *Wulsey Castle*, was not a success. In our opinion, the equipment was not designed for the service.

The four oil barges built for the Petroleum Transport Company were not successes. The explanation as given in a paper by Mr. J. L. Hibbard before the A.I.E.E. in January this year indicated that after careful investigation the difficulty was found to be almost entirely one of operating conditions. The vessels were designed for slow speed and short cruises; however, it was later decided to put these boats on relatively long trips for which they had neither the fuel nor fresh water capacity. Salt water has been apparently the primary cause of all the troubles that these ships have experienced.

Another ship, the S. S. *Tynemount* (British) was not a success, and the report states "not that there was any failure in the electrical plant."

The arguments against electric drive for ships are somewhat analogous to those presented some years ago when the electrification of mills was being discussed. It was then asked: Why incorporate the losses of electric transmission between the engine and the mill and at the same time add to the cost of the mill? Experience has shown that the electrically equipped mills can produce at a lower figure than those directly driven.

Electrically driven ships built in this country have demonstrated that electrical apparatus properly designed and installed is absolutely reliable. The desirability of installing electric propulsion machinery in a merchant vessel then becomes a study of the relative merits under known operating conditions.

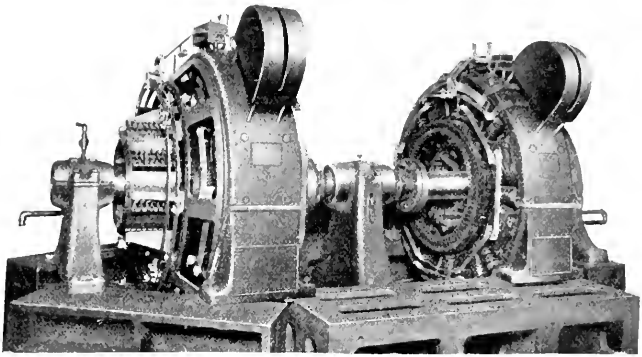
Several papers have been written on turbine-electric drive which have covered the subject quite thoroughly. Of late, interest is being shown in merchant ships of larger sizes for passenger, or combination passenger and freight service. Service requirements in some instances may not warrant operating such ships at full power the entire year. They, however, must be provided with high power propelling machinery in order to maintain a high speed schedule for months with but a few hours lay over. To assure reliability, the machinery will, of necessity, be conservatively designed and of sufficient capacity to give good efficiency at the maximum power output. Such ships fitted with two or more generating units will show a very high economy at a speed corresponding to the power output of one less unit, the speed being reduced only a small amount. Take, for example, a 25,000-s.h.p. ship built to operate six months in a year at 22 knots; this ship could with slightly less than one-half the power make $17\frac{3}{4}$ knots for the remaining six months. Under this condition one entire engine room could be shut down, and thus a considerable saving be effected not only in fuel, but in all engine room operating expenses. It is a safe prediction that, when all factors are given due consideration, electric propulsion will show an economy over other forms of drive for a large number of ships of the character under discussion.

By far the greater number of ships in merchant marine service are equipped with moderate power propulsion machinery. History will show that for many different types of vessels, and in numerous classes of service, the advantages of electric drive will outweigh all other considerations. The ability to reverse rapidly is of particular value to ships which have to navigate tortuous waterways or dangerous seas, where frequent maneuvering at full power may be necessary. For ferry boats, where a great deal of maneuvering is necessary, and where a marked gain may be realized by driving the bow propeller at reduced speed, electricity has a distinct advantage over all forms of direct drive. In cases where it is desirable to use two propellers, electric drive has the advantage of moderate cost, using one turbine-generator for the two motors.

DIESEL-ELECTRIC PROPULSION

Within the last few years there has been a great increase in the number of motor ships placed in service, both in this country and abroad. Magazines devoted exclusively to the motor ship tell us of the ever increasing number of ships being contracted for. Articles are published showing the reliability of the Diesel engine.

Just what gain can be secured in the operation of a vessel by interposing an electric link between the oil engine and the propeller does not seem obvious at first sight. A recent article in *The Motor Ship* (London) is distinctly opposed to Diesel-electric drive. This magazine should not be criticised over harshly for its prejudice, for the reason that their opinion is based on the facts as they see them. The oil engine for direct drive has been developed to a very high degree of perfection. Immense sums of money have been spent in working out different types of engines, and from accounts it would appear that while each type has its own particular advantages, a number of distinctly different engines are giving highly satisfactory results when built by manufacturing companies who have solved details in design and built the engines only of the very highest quality and workmanship. The successful engines which have been developed for direct drive are very heavy and expensive. The difficulties of manufacture increase with the larger capacities.



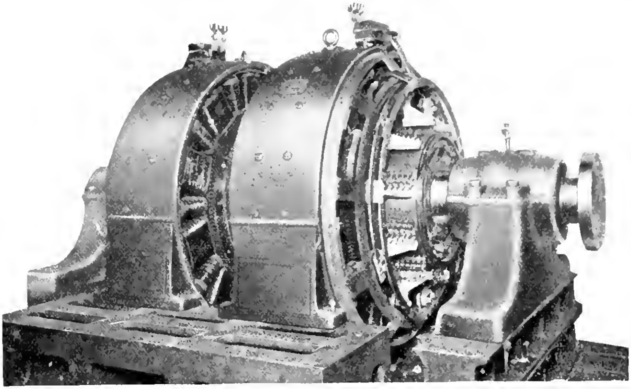
Two Direct-current Generators for Diesel electric Marine Drive on Testing Stand

The manufacturers of oil engines for propelling ships are keenly alive to the handicap of both weight and dimensions from which they suffer. We see, therefore, efforts being made to obtain a lighter engine by going to the two-stroke cycle principle. Further reduction is claimed by manufacturers of engines with opposed pistons. A recent article claims a considerable reduction in dimensions for the Camellaird-Fullagar engine of the opposed piston type. Thus we find that the oil engine is being developed for direct connection to the propeller in several distinct types, and in all probability it will be some time before any one type becomes commonly accepted as the best for ship propulsion.

The electrical apparatus would weigh about 325,000 lb., making the total weight of the direct electric drive equipment 821,000 lb. With electric drive there would be an additional saving in weight and cost by using one propeller only.

Some manufacturers of oil engines are giving very serious consideration to the development of engines more suitable for driving electrical apparatus. This does not mean that they are endeavoring to produce light high-speed machines, but without sacrificing quality and reliability they will manufacture lighter engines revolving at a somewhat higher speed for the same horse-power output.

It is not the intention to show that the direct drive of ships by oil engines is inferior in every case to electric transmission, but this article would be incomplete if it did not show that thorough investigation should always be made before deciding on the type of propelling equipment. Studies of specific cases, basing all comparisons on similar quality of apparatus, have shown Diesel-electric drive to be preferable to direct drive.



Direct-current Double Armature Motor for Diesel-electric Marine Drive

To give an idea of the dimensions of these engines: A modern four-cycle, six-cylinder, 1750-b.h.p. engine would be approximately 13 ft. wide by 27 ft. high, and a pair of these, installed complete with auxiliaries, would weigh approximately 1,800,000 lb. An estimate of an electric installation using three engines of moderate speed comes within this weight. Compared with the older established methods of propulsion, a complete installation of boilers and a marine geared turbine for a single screw and 90 r.p.m. would weigh about 60 per cent of the above.

Different makes of engines vary considerably in weight. A comparison based on an *average* of six engines of four makes for electric drive and five engines of four makes for direct drive will give an approximate idea of the advantage in weight in favor of electric drive. See Table I.

Some of the most serious problems of design are minimized when the cylinder diameters are reduced. It is not an exaggeration to say that when anything approaching the same amount of thought and money has been expended in producing reliable engines of lighter weight and higher speed as has been given to the production of the low-speed engine for direct drive, then will there be an increased number of types of ships in which electric drive will be preferable.

In comparing Diesel-electric with direct Diesel drive the following points should be given proper consideration:

1. Reliability and Simplicity

These two of necessity must be considered together and their importance outweighs all other considerations. With electric drive we should have two or more engines, and even for a single screw, two motors may be installed.

Direct drive necessitates engines with complicated valve mechanism, air storage bottles or tanks whereas, with electric drive positive control of speed and direction will be available at all times with the addition only of a few simple electrical units even for limited maneuvering and additional stand-by air compressors.

With direct drive, even with two engines and twin screws, the failure of one engine may jeopardize the safety of the ship. It is reasonable to expect, therefore, that a lower insurance rate should be secured with electric drive than with direct drive.

TABLE I

COMPARISON OF AVERAGE WEIGHTS OF 6 AND 5 DIESEL ENGINES FOR ELECTRIC AND DIRECT DRIVE, RESPECTIVELY (Engines only)

	Average h.p. Per Engine	Average r.p.m.	Average Pounds Per s.h.p.	Total h.p.	Weight
Electric Drive........	1090	238	152	3270 Using 3 Engines	496,000
Direct Drive...	1555	105.5	380	3110 Using 2 Engines	1,180,000

2. Efficiency

If the whole problem were to be settled by a comparison under one fixed condition of operation, and that one the most favorable for the direct drive engine, then indeed there would be little argument for electric transmission. As a matter of fact, however, a ship owner is interested in the all year economy, and as he knows it is often desirable to operate the ship at reduced power, he will recognize the possibility of large gain by shutting down one generating unit; for example, a ship fitted with three sets and designed to make 11½ knots will make approximately 10 knots with two.

ELECTRIC AUXILIARIES

It may be difficult to understand at this late date why it should be necessary to argue for the general adoption of electricity on ships. We know that experience has shown in practically every instance that power can be transmitted and applied more economically and with less liability of interruption by the use of electricity than by any other means.

The reason that electricity has not been more generally adopted has undoubtedly been due to the fact that up to very recently the cost of fuel, labor, and many other items entering into the operating cost of a ship would not be very materially affected by more efficient machinery and decreased maintenance. Times have changed, however, and we now find keen competition between the various maritime nations of the world, all of which are provided with ships in excess of available cargo.

The present situation is particularly severe on the merchant marine of this country, because for certain fundamental reasons it will be impossible to bring some of the operating charges down to the level of other countries with which our merchant marine must compete.

Steam-driven auxiliary machinery on ships has in the past done well enough when suitable electrical machinery had not been developed. Now, however, we find manufacturers prepared to furnish well designed and properly manufactured electrical apparatus for the various services on ships. The early motor ships with steam boilers and steam-driven auxiliary apparatus demonstrated beyond doubt the tremendous losses incident to the operation of steam-driven auxiliaries.

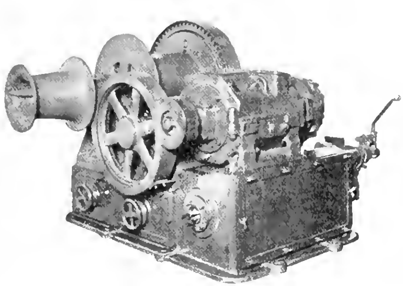
Should it be found necessary to argue this point, it might be asked if any engineer would give serious consideration to building a plant with much of the machinery mounted on the roof; every piece driven by an individual steam engine; the steam pipes exposed and uncovered on the roof; the engine room containing a multiplicity of pumps and other steam apparatus; the entire equipment installed in a minimum of space and of necessity inaccessible; a maze of pipes, valves, and fittings adding to the loss of steam by leaks and radiation. Such a plant would resemble a merchant ship with steam-driven auxiliaries.

On passenger ships there are many uses for electricity, such as ventilating fans, etc., where it is inconceivable that steam could even be considered. In such ships steam is necessary for heating staterooms, water for baths, and other purposes. This can be done most efficiently by extracting steam from one of the stages of the main turbine. There will be a considerable loss if a certain number of inefficient steam-driven auxiliaries are retained.

The most important feature to be considered in connection with electrical apparatus for ships is the ability to resist moisture. This applies to all insulation, whether washers, collars on studs, or the insulation of the windings themselves. Ample creepage surface must be provided. Apparatus which is deficient in this respect is unsuitable for application on ships, as it must be expected that with varying temperatures there will be a constant tendency to precipitate moisture.

So far as practicable small parts should be of non-corrodible material; otherwise, precautions should be taken to protect steel and iron parts either by proper painting, sherardizing, or some other approved means.

Electrical apparatus should be conservatively designed so that it will operate continuously in the tropics without deterioration of the insulation.

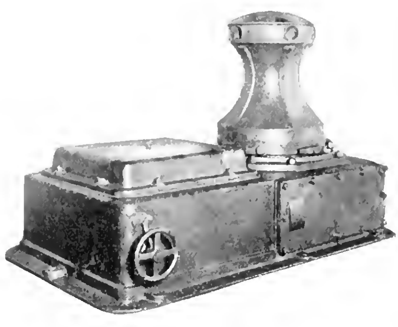


Electric Cargo Winch

All parts should be readily accessible for inspection. Covers for openings should be hinged and not bolted or held by a multiplicity of screws.

There are other details in the design and manufacture which will make the apparatus more suitable for the service. Such apparatus with fair treatment would have an indefinite life, provided the best workmanship and suitable materials are used in its construction.

There are few places where unsuitable electrical apparatus will ultimately prove so expensive as on ship board. In the layout of



Electric Capstan

a ship's installation it is very important to limit the number of sizes and types of motors installed, so that the minimum number of spares will safeguard the entire installation. To accomplish this, it may even be desirable in certain instances to provide motors of considerably larger size than necessary. This applies particularly to pumps used only intermittently.

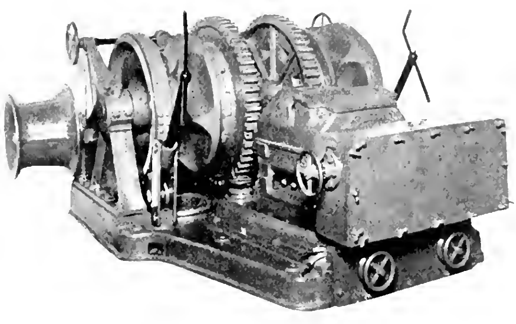
From time to time we hear the expression "water-tight" as applied to motors. To the writer's knowledge only one make of motor has been developed to operate continuously submerged. All motors, whether enclosed or ventilated, must be arranged so that water cannot accumulate inside, as we know every piece of electrical machinery will tend to sweat with varying temperatures. Further, there is always a likelihood that one of the covers may not be closed perfectly tight, allowing water to enter, either from rain or seas washing over the deck. An endeavor to maintain an absolutely "water-tight" motor will be useless expenditure.

Deck Machinery

All ships are fitted with a certain amount of machinery mounted on deck. This consists of anchor windlass, steering gear, capstans and winches, also, in some cases, special machinery for mooring, towing, or other purposes. The service is generally intermittent.

Where the service requires continual variation of speed and direction, control may be obtained either electrically through the motor; mechanically, by shifting gears; or hydraulically by means of a speed reducing pump and oil motor. The electrical means is generally employed except for the steering gear. For this service the hydraulic gear, either Waterbury or Hele-Shaw, is commonly installed.

Anchor windlasses are generally designed to raise both anchors simultaneously with a chain speed of approximately 20 ft. per min. It quite often happens that the power required for lifting the anchor is twice that for the cargo winches. A very desirable arrangement, therefore, is to use two cargo winch motors on the anchor windlass.



Electric Anchor Windlass

Warping winches and capstans are generally fitted with compound or shunt-wound motors and preferably should be arranged so that the direction of rotation may be reversed. A rope speed on the drum of 150 ft. per min. is quite common. In particular cases mooring winches have been arranged for very high pull, 20,000 lb. at a speed of about 30 ft. per min. for such service as mooring tankers near pipe lines. There are many varieties of cargo winches. The conventional electric winch is an adaptation of the spur gear steam winch using an electric motor in place of the steam engine. It must always be recognized that the cargo winch is at best somewhat of a compromise, as it cannot be designed for any particular class of cargo. It is quite common to arrange the winches to have a rope speed of approximately 150 ft. per min. for five tons and 250 ft. per min. for one ton. Individual winches are more flexible than arrangements using one motor to drive a number of drums through gears. It is very doubtful if this latter arrangement will be generally adopted.

Second only to the main propulsion machinery, the steering gear is most vital to the safety of the ship. Therefore, too much stress cannot be laid on the reliability factor. The motors, in all probability, will not be exposed to the direct action of the rain and waves, bu the compartment where the tiller and steering motor are located is liable to be damp, and therefore, all electrical equipment should be designed accordingly. The movements of the tiller are controlled from the wheel house by various means. Both electric and hydraulic telemotors are in use and more or less trouble has been experienced with both types. There is no reason why electric telemotors, if properly designed and built, should not be entirely reliable and free from the defects inherent with the hydraulic.

Below Deck Machinery

Generally speaking, some form of enclosed ventilated motor will be most desirable, although in certain protected places the open type motor may be entirely satisfactory. All motors should be fitted with screens to prevent rodents damaging the insulation. It would seem desirable that the motors, which are vital to the safety of a ship, be provided with automatic starters, so that these motors will start again with the least delay should the power be interrupted at any time. The other motors should be arranged so that they will be cut out in the case of low voltage, to be re-started by the engineer.

In all industries we find that the use of electricity has been generally accepted, not because some one advocated it, not because of theoretical reasons, but only because it has proven to be the most economical way of utilizing power. Ultimately we shall find the same condition on our merchant ships. The engineer realizes the necessity of electrifying our merchant ships. His immediate problem, therefore, is to study conditions and so familiarize himself with all phases of ship operation that he will be in a position to study specific cases for ship owners and show them what is the most efficient equipment for their ships. The first step always requires the greatest effort. As electrical installations increase in number, the necessity for argument will disappear and engineers can then devote their entire time to studying means and methods of perfecting the apparatus.

Lubricants for Electric Street Railways: Summer and Winter Grades

By George R. Rowland

Supervising Engineer, The Texas Company, New York City

This is a timely article on the choice of lubricating oils for electric railway motors, journals, gears and air compressors to give the best results with the changing temperature of the seasons. In the northern sections of our country the range between winter and summer temperatures will exceed 100 deg. F. in many localities and a moment's thought on the subject shows that it is unreasonable to expect that one grade of lubricant will provide satisfactory lubrication at these extreme temperatures. Efficient operation and low maintenance demand a change in the grade of lubricants with change in season in localities where large variations in temperature prevail, that is, the viscosity variation of the lubricant for each season should correspond with the average temperature difference.—Editor

During the thirty-four years following the official opening of the first electric street railway at Richmond, Va., in 1887, the improvements in electric street railway equipment and operation have been many. This constant development has resulted in our present highly efficient cars for city and interurban service. Motors are more efficient and will last longer with lower repair costs than in the earlier days, cars are heavier and run faster, and in order to meet the increased traffic various appliances have been developed for improving the safety of operation and eliminating accidents. The high speed interurban car is quite different from the old horse-drawn tram car.

While this development of equipment has gone on, the improvement in lubricants, unfortunately, had not until very recently kept pace, and even today many railways are still using the same lubricants originally developed for the first horse-drawn street cars.

One of the greatest of recent improvements in lubrication is the use of different grades of lubricants for summer and winter. The rolling stock equipment of electric street railways is directly exposed to atmospheric temperatures, which vary in different localities of the country. These varying temperatures should always be given careful consideration in selecting lubricants for such equipment.

Every man who has handled or used oil knows that lubricating oils become thick and sluggish in cold weather. Journal bearings, axle bearings, and motor armature bearings of electric street railway cars are lubricated by means of waste saturated with oil.* In order that proper lubrication may be secured, it is necessary that the waste feed the oil to the bearings in a uniform manner. The supply of lubricant is influenced, primarily, by the capillarity and the fluidity of the oil at the operating temperature.

The first of these characteristics, capillarity is influenced by many factors, among them being the surface tension of the oil, which probably decreases slightly as temperatures are raised, and the ability of the oil to saturate the waste. Waste, of course, is a very non-uniform material, being made of varying percentages of wool, cotton and fiber, each of which has a different effect upon the capillarity of the oil. Proper capillarity of a lubricant is secured by practical experience which results in the selection of suitable constituents for the oil.

The other important characteristic affecting the rate of oil feed is fluidity. Since fluidity, which is usually expressed in terms of viscosity, is dependent upon temperature, the operating temperature is the determining factor in selecting suitable grades of lubricants for summer and winter service. An idea of how oils are affected by temperature changes is shown in the temperature viscosity chart of various oils, Chart 1, some of which it will be noted are not suitable for the lubrication of electric street railway cars, and are only shown for comparative purposes.

Chart 2 shows the average temperature through the year for a period covering the past thirty-five years at five of the principal cities in the United States. These figures are furnished by the United States Weather Bureau at New York. Attention is called to the very uniform temperature in the city of San Francisco throughout the entire year. Evidently summer and winter grades of lubricants are not necessary in this city in order to secure satisfactory results.

During the months of June, July, August and September the average temperature at

* With the exception of ball bearings and the older grease lubricated motor bearings.

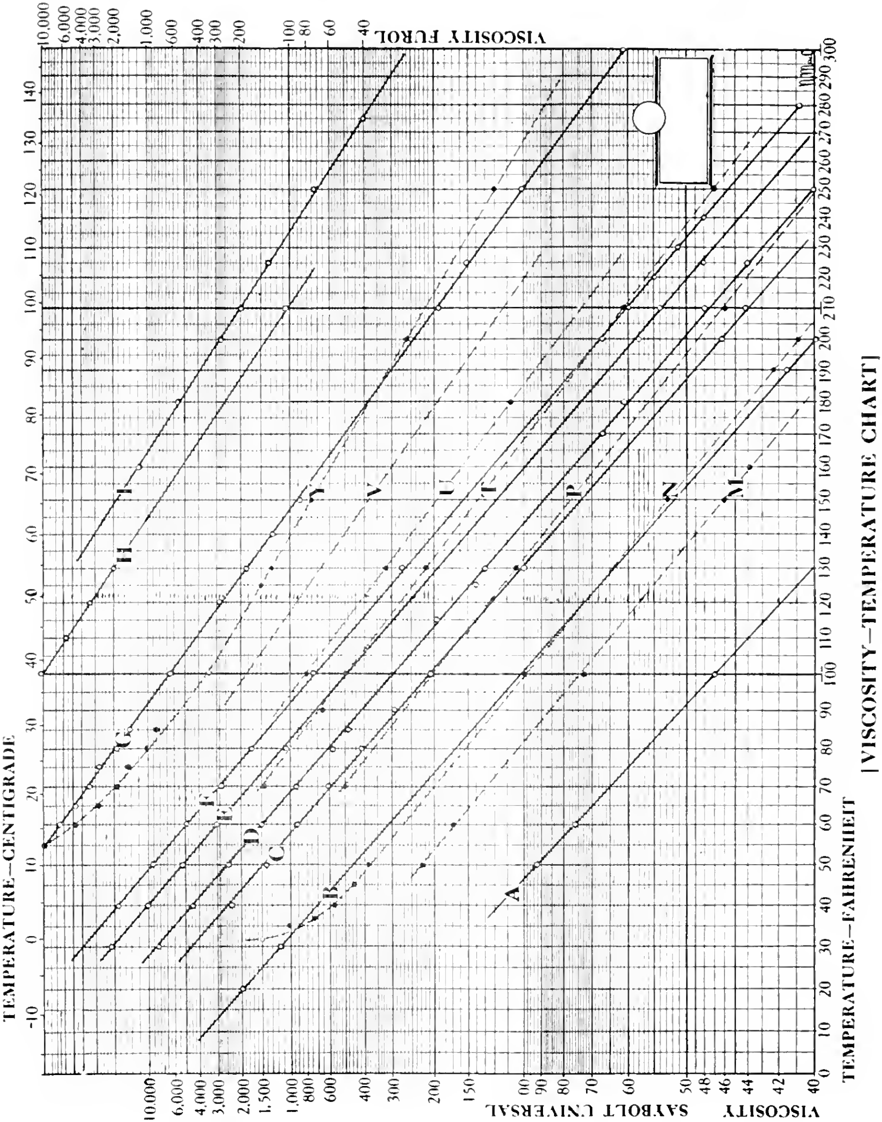
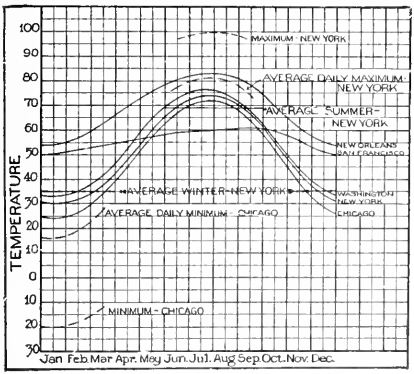


Chart 1. A to I Represent Well Refined Naphthene Base Oils Which Are Practically Free from Paraffine and it Should be Noted That the Viscosity Lines Are Almost Parallel. The other oils are from a different class of crude and while the viscosities are similar the lines have a different slope and not all of them are straight

New York City is 69 deg. F., whereas during the months of December, January, February and March the average temperature is 35 deg. F. Washington, D. C., is about 3 deg. hotter in the summer than New York, and Chicago is about 6 deg. colder in the winter. In New York City around the first of August the average daily maximum temperature is 81 deg. and at intermittent intervals it sometimes reaches 100 deg. F., so that when selecting an oil for an average temperature of 69 deg. F. we must at the same time allow a margin sufficient to take care of temperature conditions at 100 deg. F.

At the lower end of the temperature scale we find Chicago, with an average daily minimum temperature of 16 deg. F. during the month of January and a minimum temperature for short intervals of as low as 20 deg. below zero. Oils for the latter service should be sufficiently fluid to feed to the bearings at this temperature.

Obviously in the winter months the oil should be sufficiently low in viscosity to feed to the bearing surfaces in proper quantity and in the summer months should be high enough in viscosity to prevent too rapid draining from the bearings. The ideal condition would be to have the oil at its average



Furnished by the U. S. Weather Bureau

Chart 2. Average Atmospheric Temperature Throughout the Year in Various Cities

summer operating temperature of the same viscosity as at its average winter operating temperature. Such a condition, of course, is a physical impossibility when one oil is used, but when two oils are used, the viscosities and other physical characteristics can be selected to meet these conditions in the proper manner.

For equipment which is operated continually out of doors such as electric street railway cars, the viscosity of the summer grade for the vicinity of New York City

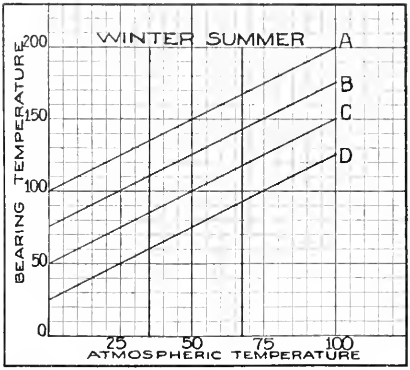


Chart 3. Approximate Variation of Bearing Temperatures with Atmospheric Temperature

should be the same at 69 deg. F. as the winter grade at 35 deg. F. In other localities the difference in viscosities of summer and winter grades should be in conformity with their average summer and winter temperatures.

Practical experience has shown that under the severest sort of service during the summer months, a straight mineral oil having a Saybolt viscosity of 100-105 seconds at 210 deg. F. will give the most satisfactory service in motor armature bearings, axle bearings and journal bearings. An oil of lower viscosity will not afford a sufficient margin of safety to take care of the high temperatures which frequently occur. A higher viscosity is unnecessary and as the frictional temperature of a bearing increases with the increased viscosity of the oil, the maximum viscosity given above should not be exceeded.

Chart 3 shows the operating temperature of four bearings, A, B, C and D, corresponding to varying atmospheric temperatures. Bearing B, for instance, under average summer temperatures, runs at 143 deg. F. At this temperature the summer grade of oil referred to has a Saybolt viscosity of 390 seconds. If this same bearing were cooled to 109 deg. F., the average winter working temperature, the summer grade of oil would be entirely too viscous. For satisfactory results at the latter temperature the viscosity of the winter grade should also be approximately 390 seconds Saybolt. Referring to the curve shown in Chart 4, it will be observed that the winter grade of electric car oil is just slightly lighter than this viscosity at the normal winter operating temperature.

It is desirable to make the winter grade of electric car oil slightly lighter than the corresponding viscosity of the summer grade, as explained above, so that it will feed properly even under the very low temperatures of severe or, rather, abnormal weather.

In considering the lubrication of electric railway air compressors, we find from experience that two grades of lubricants are also necessary. The practice in the past has been to use the same viscosity compressor oil the year around, and in providing an oil of sufficiently low pour test for winter use it was necessary to use an oil of such low viscosity as to make it unsuitable for efficient lubrication during the summer months. While the lubricating requirements of an air compressor are in many respects different from those of bearings and gears, they are influenced by temperature variations and it is essential that the same consideration be given to viscosity in this case as is demanded

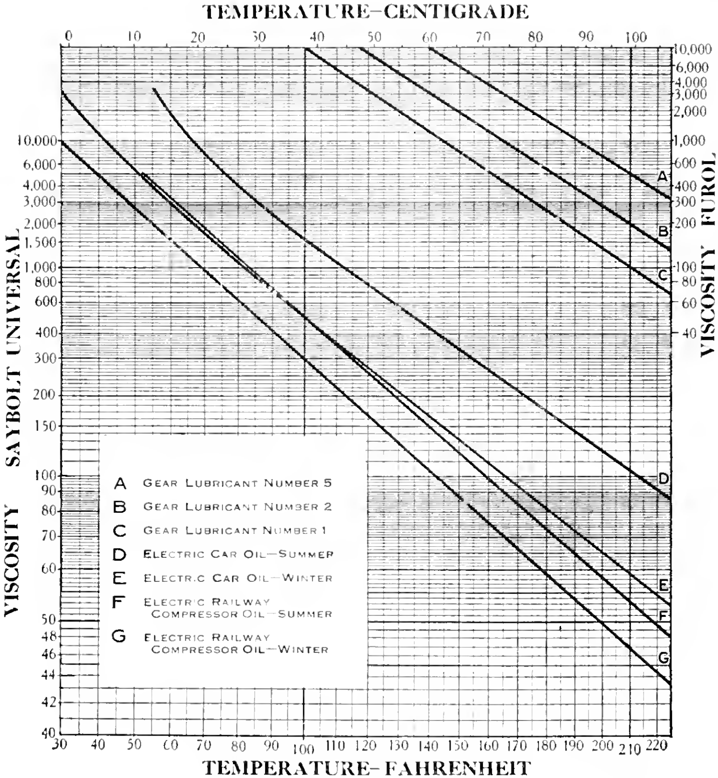


Chart 4 The Viscosities of Various Lubricants Recommended for Electric Street Railways at Different Temperatures

in other classes of lubrication. The influence of atmospheric temperatures is modified to some extent by the heat of the compressed air, and the average operating temperatures are those which must be considered in selecting the viscosity.

An air compressor oil for winter use, having a viscosity of 300 seconds Saybolt at 100 deg. F. will provide a satisfactory seal for the piston rings and will maintain the functioning of the air compressor at its proper efficiency when the compressor is in a normal mechanical condition. However, when piston rings and cylinder become worn, it is necessary to use an oil of higher viscosity in order to secure proper piston seal.

Since the compressor draws air from the inside of the car, which is heated in the winter, and therefore somewhat warmer than the outside air, and as the car is usually cooler than the street temperature in the summer, the difference in the viscosity of the summer and winter grades need not be as great as in the case of the electric car oils. The effect of summer temperatures is great enough to require the use of an oil of at least 500 seconds Saybolt at 100 deg. F., and when such an oil is used there will be an improved piston seal, thereby increasing the compressor efficiency and at the same time greatly reducing the oil consumption during the summer months. This improvement over the use of the winter grade of compressor oil, throughout the entire year, is an important factor in electric street railway air compressor performance.

Gears also are exposed to the extremes of temperatures. The summer and winter grades of gear lubricant should therefore have a viscosity variation corresponding directly with the average temperature difference. Gear lubricants are of necessity more viscous than the other lubricants referred to, so that it is practically impossible to measure their viscosity at their operating temperatures. On this account, all viscosities of gear lubricants are measured at 210 deg. F., and calculated from curves for actual operating temperatures. On the basis of 5,000 seconds Saybolt at 210 deg. F. for the summer grade and 1,000 seconds at 210 deg. F. for the winter grade, these respective gear lubricants will have exactly the same viscosities at the average temperatures in summer and winter weather. Of course where average winter temperatures are higher than the average of New York City, the viscosity of the winter gear lubricant should be raised to 2,000 seconds Saybolt at 210 deg. F.

For equipment so directly affected by atmospheric conditions as electric street railway cars, it is absolutely essential that careful attention be given to the use of proper grades of lubricants for summer and winter. The use of lubricants of the correct viscosity will result in minimum power consumption through decreased frictional losses and increased life of bearings and all parts affected by frictional wear.

To get these results it is essential that the grades be changed at the proper time of the year, so that winter grades will not be used too late in the spring and summer grades too late in the fall.

From the temperature Chart 2 it will be seen that the temperature half way between average summer and winter occurs during the last week in April and the last week in October. Consequently the change in the grades of lubricants should be made about this time, but instead of waiting until the exact date arrives to make an abrupt change, it should be started at least ten days or two weeks before a general change of temperature is expected. In the spring it will be found that compressors, gear cases and waste are supplied with winter lubricants, which will continue to have an influence upon lubrication until they have been entirely eliminated from use. The same condition exists with summer lubricants in the fall. On this account it is advisable to start the gradual use of the summer grade on inspection periods, commencing about April 15th and the winter grade about October 15th. The percentage of the summer oil applied will slowly raise the viscosity of the oil already on the equipment and quite in accordance with actual temperature changes. The reverse will occur in the fall, as the winter oil is gradually applied, thereby bringing down the viscosity to the proper point. In this way any unseasonably cool or warm days will automatically be taken care of in proper manner.

Conditions vary in different parts of the country and it is always necessary to exercise judgment as to the exact date selected to change lubricants to meet conditions, and as it would be extremely wasteful to consider cleaning all oil receptacles at any given period due allowance should be made as to seasonal conditions so that waste can be avoided by gradually increasing or reducing the viscosities of the oils as normal temperature conditions demand.

Cottrell Electrical Precipitation Installation at the Duquesne Reduction Company, Pittsburgh, Pa.

RECOVERY OF FUME LOSSES FROM FURNACES TREATING TIN ORE AND DROSSES

By N. J. Hansen

Construction Engineer, Research Corporation

A modern electrical precipitation installation, the purpose of which is to recover the valuable metallic particles carried in the flue gases from tin smelting furnaces, is described in this article. The construction of the precipitator, which is of the pipe type, is illustrated in detail, as is also the electrical equipment. It is interesting to note that from the gases emanating from furnaces treating a total of 20 tons of tin drosses, 2600 pounds of solids, analyzing 24 per cent tin, 4 per cent lead, and 40 per cent zinc are collected every 24 hours.—Editor.

The construction of the present installation of the Cottrell electrical precipitation process at the plant of the Duquesne Reduction Company, Pittsburgh, Pa., was completed by the Research Corporation of New York, in August, 1920. It replaces the original installation which had been in operation for a number of years and which proved inadequate for the increased plant capacity. The precipitator is used to recover the metallic values* carried by the gases from two reverberatory smelting furnaces each of which has a capacity for treating approximately ten tons of tin drosses every 24 hours.

Related Plant Operations

The flue system from the furnaces to the stack is shown in Fig. 1. The gases are led from the furnaces through individual flues into a common flue 4 ft. 8 in. in diameter, through which they pass to a steel header flue of the same diameter. From this header flue, they pass through separate openings into the bottom headers of each of the three precipitator units. The gases then pass up through the vertical precipitator pipes, where the suspended particles are removed by electrical action.† The clean gases then pass from the upper header of the precipitator units through three separate outlet flues to a concrete chamber. From this chamber they pass either directly to the stack or through a by-pass and fan to the stack. This stack is constructed of steel, is brick lined, and is 3 ft. 6 in. in diameter and 130 ft. high.

* In metallurgy, the word "values" is commonly used in connection with those materials which are of sufficient market value to warrant recovery.—Ed.

† A complete and detailed description of this electrical cleaning action was given in the article, "Cottrell Process of Electrical Precipitation," under the sub-heading, "Theory of the Cottrell Process," General Electric Review, November, 1921.

Precipitator Construction

In accordance with general practice, the precipitator at this plant is sub-divided into three units or groupings of the precipitator pipes. Each of these units has separate gas

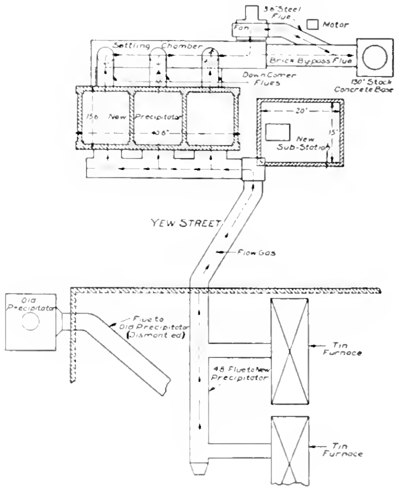


Fig. 1. General Layout of the Duquesne Reduction Company's Precipitator Installation

connections and electrical control, thus permitting flexible operation dependent upon the plant operating conditions. Each unit consists of 60 precipitator pipes, 56 of which are 10 in. in diameter and 15 ft. long, the remaining 4 being 14 in. in diameter and 16 ft. long. A concrete bottom header and a steel top header are provided for each unit. Such a precipitator unit has a rated capacity of approximately 10,000 cu. ft. of gas per minute at the temperature of the gas at the point of treatment, which may vary from 150 to 600 deg. F. The general location of this installation is indicated in Fig. 1. The general appearance both during construction and after completion is shown in Figs. 3, 4, 5 and 6; and the general type of construction is illustrated in Fig. 2. Normally, only one or two units are operated at a time, the third being a spare.

Bottom Header

The bottom header of these precipitator units is of the hopper type constructed of concrete properly reinforced with steel. The structure consists of a rectangular chamber, the inside horizontal dimensions of which are 12 ft. long and 13 ft. 6 in. wide.

The top of this bottom header is 20 ft. above the ground level and consists of a concrete slab 6 in. thick provided with suitable holes through which the precipitator pipes project into it, as shown in Fig. 2.

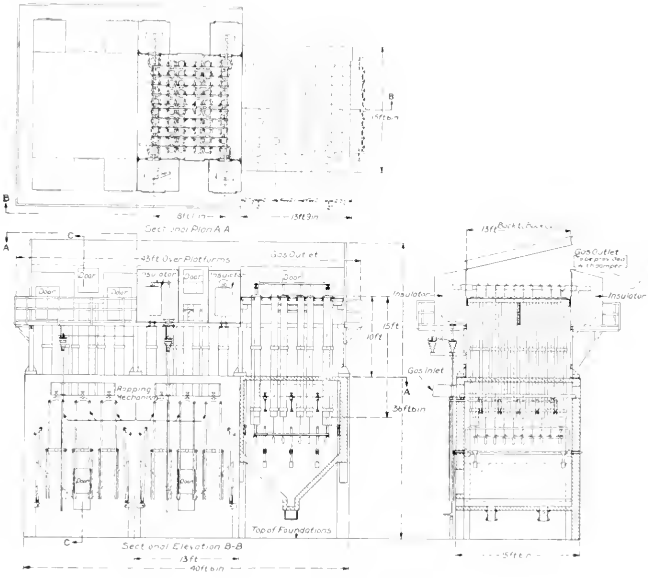


Fig. 2. Construction of the Three-unit Cottrell Precipitator at the Duquesne Reduction Company

As indicated in Fig. 2, these three precipitators are so built together as to form a single installation of three separate units. The construction of each of the units is identical, the intermediate walls being common. In general, the structure of the precipitator unit may be divided into the following parts: the concrete bottom header or dust chamber; the steel super-structure and top header; the precipitator pipes or collecting electrodes; the discharge electrodes with supporting framework, cleaning and rapping devices; and the high-tension connections and switches.

The bottom of the structure is constructed in the form of a hopper whose sides slope at angles of 45 deg., terminating in a channel at the bottom so it may be equipped with a screw conveyor in the future. There are at present two openings in the bottom of each unit, provided with gate valves through which the precipitated dust and fume can be removed. The cubical content of this bottom header is approximately 1900 cu. ft.

The chamber is supported at its four corners by reinforced concrete columns which extend up through the chamber in the form of pilasters. Each of these columns is 9 ft. 3 in. high and 21 by 18 in. in cross section, intermediate columns being common to the adjoining precipitator unit. Access to the

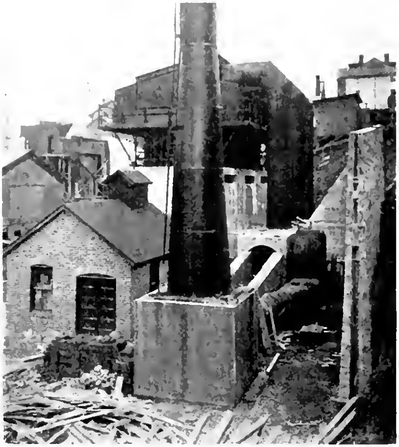


Fig. 3. Installation Under Construction Showing Exit Connections

bottom header is made through doors provided in one end of the hopper. Gas is admitted into each of the bottom headers through an opening 8 ft. wide by 18 in. high located near the top of the bottom header. The gases on entering the bottom header are forced to travel downward before entering the precipitator pipes which extend into the bottom header and thus equal distribution of the gases among the various pipes is obtained.

Butterfly dampers provided in the inlet flues of the precipitator make possible the regulation of the volume of gases passing through each unit.

Steel Structure and Top Header

The steel structure erected on top of the bottom header is supported by four corner columns made up of angles placed back to back suitably strengthened by diagonal bracings on the sides and ends. These columns are held in place by anchor bolts inserted in the concrete bottom header. At a point approximately 10 ft. above the top of the concrete header is a framework made up of channels, located as indicated in Fig. 2, between which the pipes are placed vertically. On top of this framework is placed the top header plate which is provided with holes to accommodate the precipitator pipes. The plate is so placed that the holes are directly over those provided for the same purpose in the top of the bottom header.

This steel structure, above the level of the top header plate, is enclosed by sheet metal on all sides, the intermediate wall between the adjoining precipitator units being common. There are holes provided in both sides of this sheeting through which extend the busbars for supporting the discharge electrode framework. Doors are also provided in both sides of the top header through which access to the interior is obtained. A sloping roof of sheet metal is provided on top of the structure, 8 in. above which is placed an asbestos protected corrugated sheet roofing. The outlet flue is attached to one side of the top header where an opening sufficient for the exit gases is constructed.

Another framework is provided 6 ft. 6 in. above the top of the concrete bottom header and consists of angles and channels projecting beyond the supporting columns. This framework serves as a support for a working platform that extends around the top head-

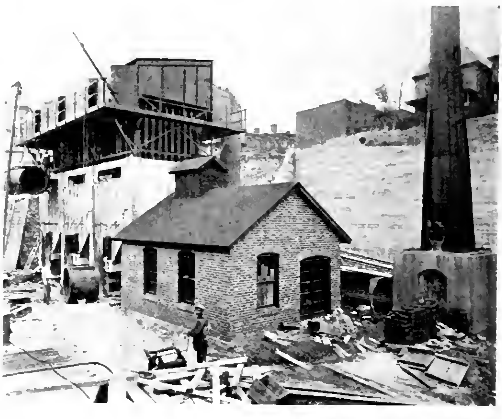


Fig. 4. Installation Under Construction Showing Inlet Connections

ers of the precipitator units. On this framework are located the supporting insulators, which are enclosed in insulator boxes extending from the level of this platform to a point 6 ft. higher, from which latter point they slope up to meet the walls of the top header. These insulator boxes are of rectangular shape as indicated in Fig. 2, and are provided with doors to permit ready access to the insulators.

The design of this top header is such as to give a gas-tight compartment with a content, exclusive of the insulator boxes, of approximately 900 cu. ft.

Collecting Electrodes

The collecting electrode pipes are fabricated of steel with spiral lock seams. At the upper end of these pipes an angle flange is welded to the pipe for its support. Collars welded to the pipe approximately 6 ft. 6 in. and 14 ft. respectively from the upper end present a reinforced surface on which the pipes can be rapped for cleaning.

The pipes when installed are supported by the top header plate and extend through the holes in the top header plate and the holes in the top of the bottom header. When properly plumbed, concrete is placed on the top header plate to the level of the ends of the pipe, thus making a smooth surface in the top header which can easily be cleaned.

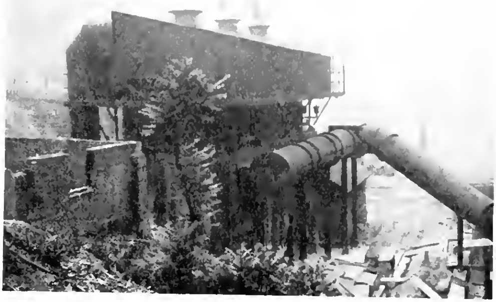


Fig. 6. General View of Completed Installation

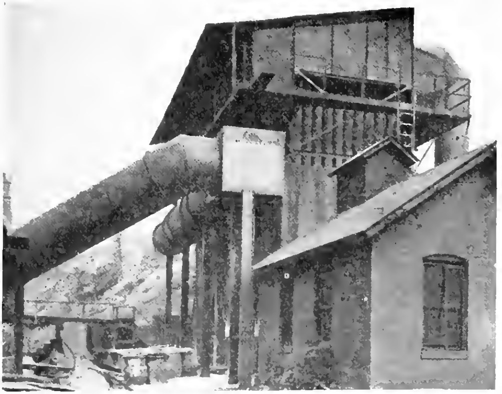


Fig. 5. Completed Installation, Showing Inlet Connections, Concrete Hoppers and Pipes

Discharge Electrode System

The discharge electrodes which hang down through the axial centers of the precipitator pipes are supported from a framework located about 16 in. above the top header plate. This framework is supported by corrugated porcelain post type insulators, approximately 3 ft. high, located in the insulator boxes previously described, and consists of the busbars which extend across the top header and through the holes provided in the side plates of the top header. On top of these busbars are bolted spacing angles as indicated in Fig. 2. To these spacing angles are bolted clips from which the discharge electrodes are suspended.

The discharge electrodes for the 10-in. pipes consist of Triumph chain held taut at the base by cast-iron weights. The electrodes for the 14-in. pipes are made up of $1\frac{1}{2}$-in. extra heavy pipe to which are fastened four longitudinal fins. These latter electrodes extend through the 14-in. diameter pipes and are rigidly fastened to the busbars in the top header and support a framework of similar construction in the bottom header. The chain electrodes pass through clips attached to this lower framework. The rigid construction of this discharge electrode assembly prevents any swaying or swinging of the electrodes during the operation of the precipitator. The insulators themselves are protected from dust by sheet metal hoods placed over them. Doors are provided in the hoods to permit access to the insulators when desirable.

Cleaning and Rapping System

Rapping devices are provided for removing the material collected on both the pipes and the discharge electrodes. The rappers for the pipes consist of a shaft which is located centrally in each one of the three aisles between the precipitator pipes, to which shaft are attached five arms, each of which carries a cast-iron weight. The shaft is operated from a system of levers located outside of the precipitator, and when rotated the cast-iron weights strike sharp blows on the pipes. The location of this system of rappers is indicated in Fig. 2.

The collected material is removed from the chains by means of a rapping system consisting of a shaft to which is attached a pipe framework which is operated from outside the header in a manner similar to that of the pipe rappers. This framework when rotated strikes against the chains thus removing the dust. To prevent the discharge electrode framework from swinging while being rapped, a locking device is provided which engages with the framework in the lower header and holds it in place during the interval of rapping only.

High-tension Connections and Switches

The high-tension lead from the substation extends to insulators located on the side of each precipitator unit. On top of this insulator is placed a spiral spring. Another insulator which is connected to the discharge electrode framework of the precipitator unit is carried on a shaft which can be rotated by hand from the ground. On top of this pivoted insulator is an arm which makes contact with the spring on the top of the line insulator when rotated to the proper position. In this way each precipitator unit can be connected or disconnected electrically without interfering with the operation of the other units.

Electrical Substation Equipment

The electrical equipment for furnishing the high-voltage unidirectional current for the operation of the three precipitator units is located in a brick substation as shown in Fig. 1.

The operation of this equipment is as follows: The power supply is 220-volt, 3-phase, 60-cycle alternating current. One phase of this is connected to the primary of a special high-voltage transformer, the primary of which is provided with taps to enable the operator to vary the high-voltage alternating current.

The high-voltage alternating current is transmitted to a mechanical rectifier or "reversing switch" which is driven in synchronism with the power supply by means of a 3-h.p., 3-phase synchronous induction motor. This synchronous switch or rectifier is so arranged that a contact is made over approximately 90 electrical degrees of the wave twice during each cycle. By means of suitable switching arrangement the negative impulse of the wave is permitted to pass directly to the line. Then the contact is broken, and by the time the polarity in the transformer has been reversed the connection between the terminal and the line have also been reversed so that again the negative potential passes directly to the line. This gives not a true direct current but a unidirectional intermittent flow of current having 120 impulses per second. However, the electrical field between the electrodes in the precipitator is maintained at somewhere near a constant potential by the condenser action of the precipitator itself.

In order to obtain close regulation between the voltages supplied by the various ratio taps of the transformer, a non-inductive series resistance is provided in the primary circuit. This resistance is divided into eight steps and so arranged that the amount which is inserted in the line can be controlled from the switchboard.

Two complete sets of electrical equipment are installed for operating the precipitators. One of these electrical sets is new and consists of the following:

- One synchronous induction motor
- One special high-voltage transformer of 25-kv-a. capacity with taps provided in its primary winding so that with a primary voltage of 200 volts a high-tension voltage of 55,000 to 75,000 volts can be secured
- One mechanical rectifier
- One switchboard with meters and switches, resistances and accessory equipment.

The other set of electrical equipment consists of the equipment originally used on the old precipitator at this plant. This equipment was overhauled and put in first class condition and consists of the following:

- One synchronous induction motor
- One special high-voltage transformer of 10-kv-a. capacity with taps provided in its primary winding so that with a primary voltage of 200 volts a high-tension voltage of 50,000 to 100,000 volts can be secured
- One mechanical rectifier
- One switchboard with switches, meters resistances and accessory equipment.

Both of these electrical sets are located in the substation building as indicated in Fig. 7. Guard screens are installed in front of the equipment that carries high-voltage electricity, and doors are provided to permit access when necessary.

The high-tension lead from each set of electrical equipment terminates in a common busbar which extends through a monitor on the roof. A porcelain bushing protected by the roof from the weather is provided in one side of this monitor. Through this bushing the high-tension line extends to the switches of the precipitator units. A high-tension switching arrangement is provided in the electrical house to enable the operator to use either of the electrical sets.

Operation

Since the installation has been in operation a recovery of well over 95 per cent of the metallic values carried in the gases entering the precipitator has been maintained. The electrical power consumption of the equipment with two precipitator units in use has averaged 300 to 500 kw-hr. per 24-hr. day. The precipitator pipes and discharge electrode chains are rapped at periods varying from one to two hours. Three to five minutes are required for the rapping of two units. At the time one precipitator unit is shut down for rapping and cleaning, the gases are passed through the other two units so that at no time do any of the gases escape to atmosphere without treatment in the Cottrell precipitator.

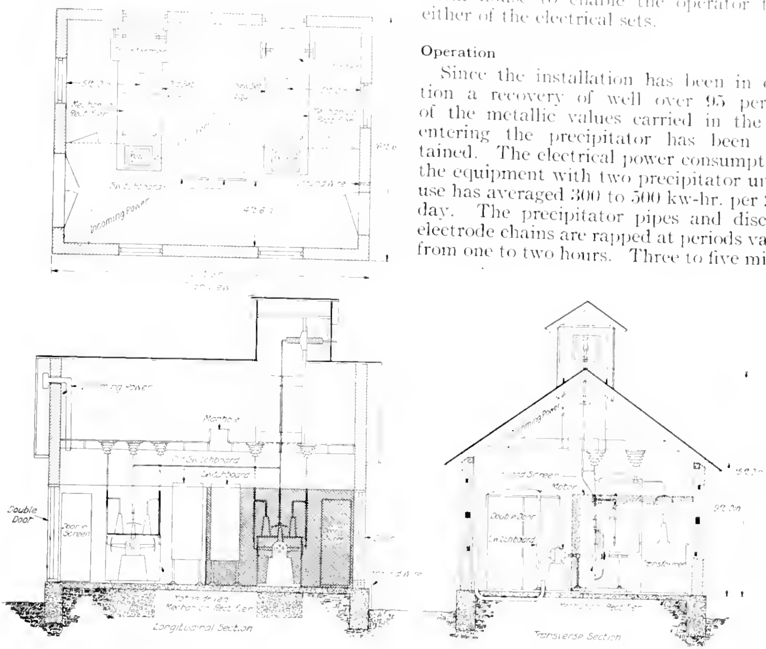


Fig. 7. Layout of Substation Building for the Duquesne Reduction Company's Precipitator Installation

Recovery

The precipitator recovers approximately 1300 lb. of material per furnace during a day's operation. This material varies widely in composition but the average analysis would be as follows for the principal metallic constituents:

Tin	24 per cent
Lead	4 per cent
Zinc	40 per cent

all in the form of oxides and chlorides.

Cost of Operation

The cost of an installation similar to the one at the Duquesne Reduction Company completely erected and placed in operation by the Research Corporation at the present time would be approximately $40,000 to $50,000.

One operator is in charge during each of two shifts per 24 hr. General repairs and maintenance would not exceed 2 per cent of the investment and the depreciation would not exceed 10 per cent overall.

Automatic Substation at Christchurch, New Zealand

By Nelson Jones

National Electrical and Engineering Co., Ltd., Christchurch, N. Z.

This article describes in detail how an automatic substation application in New Zealand solved the problem of supplying increased power economically to a remote section of a street railway system. Numerous similar applications have been made in the United States and others are contemplated as soon as street railway conditions become established. It would seem that the managers of railway properties are becoming familiar with the reliability and adaptability of the automatic substation.—Editor.

Christchurch, the chief city in the South Island of New Zealand, and the second largest in the Dominion, is situated on the Canterbury Plains, on the east coast of the island. The total area of the city is approximately 4,500 acres, with a population of 100,000 people. The population served by the Tramway Board's system is approximately 93,000, with a total single track mileage of 74 miles, 48 chains, including loops. The total number of electric cars is 65, with 89 trailer cars. The whole of the system is practically flat and without grades of any kind, and one, two or three trailer cars are used as traffic demands, except on the Cashmere Hills section, where severe grades of 9 per cent and 10 per cent are met with for a distance of about two miles.

Fig. 1 shows the layout of the system, and it will be noticed that all lines converge and run through the center of the city at Cathedral Square.

The main power house, located at Falsgrave Street, was originally a steam turbine station, but upon the advent of the Government Lake Coleridge hydro-electric scheme, alternating current at 11,000 volts, 3 phase, 50 cycles was available, and arrangements were made for a supply of power from this source. The original power house is now under normal conditions a converter station, with one 1000-kw., and one 500-kw. synchronous converter, although steam is always available at short notice, and the whole capacity of the station, 1000 kw. at 600 volts d-c. and 1500 kw. a-c., can be utilized as a standby for the tramway system itself and for the more important consumers on the Government a-c. lines.

The Cashmere Hills section was originally fed from the power house by one 0.4 positive and one 0.4 negative feeder tapping in at the far end of the section, each feeder being 3 miles, 32 chains long. Under ordinary service conditions, with two cars on the Hills section at the same time, the voltage drop was excessive, and it was found difficult to maintain a reasonable car speed or adhere to the time table, and in holiday time, with increased traffic, conditions were even worse. Owing to the rapid growth of the Cashmere Hills district as a high-class residential area, and also due to the heavy traffic on Sundays and holidays, when thousands of people visit the Hills for the sake of the outing and the fine view, the Board found it necessary to increase the service and speed up the time table on this section, and after various alternatives had been considered and rejected, it was eventually decided to install a 300-kw. automatic substation at the foot of the Hills, power being supplied from the Government 11,000-volt, 3-phase, 50-cycle lines which run close to the Board's track at this point.

The plant was ordered from the General Electric Company in June, 1919, and delivered between February and September, 1920. The substation equipment comprises the following:

- One 6-pole, 300-kw., 1000-r.p.m., 550-volt synchronous converter.
- One 300-kv-a., 11,000/445-volt, 50-cycle, 3-phase, oil-cooled, main transformer.
- One 5-kv-a., 11,000/110-220-volt, 50-cycle, control transformer.
- One 15,000-volt, motor operated, oil circuit breaker.
- One set of 15,000-volt, three-phase, oxide film lightning arresters.
- Automatic control panel.
- Converter contactor panel.
- Motor operated controller.

The required voltages and frequency, being unusual in the United States, called for some slight modification in previous design and for fresh development work, but otherwise the equipment is practically standard and its details and general operation have already been described at length in previous issues of the General Electric Review.

The substation building is of brick, 25 ft. by 25 ft. by 16 ft. high, with an entrance tower for the high tension lines 25 ft. high. An annex, 16 ft. by 16 ft., is utilized as a transformer distributing station for local consumers from the Government lines. Ventilation and lighting are provided by glass louvres specially screened to prevent entrance of dust, and the cement floor has been well oiled and painted, with the same end in view. Extra heavy roof beams above the rotary and transformer provide means for handling and lifting. Trenches built into the floor, covered with iron checker-plates, carry all control wires and main cables, and considerable trouble was taken to avoid crossing or mixing of wires, so that any control wire or cable can be quickly and readily identified.

Erection was commenced on January 17, 1921, and as this was the first automatic sub-

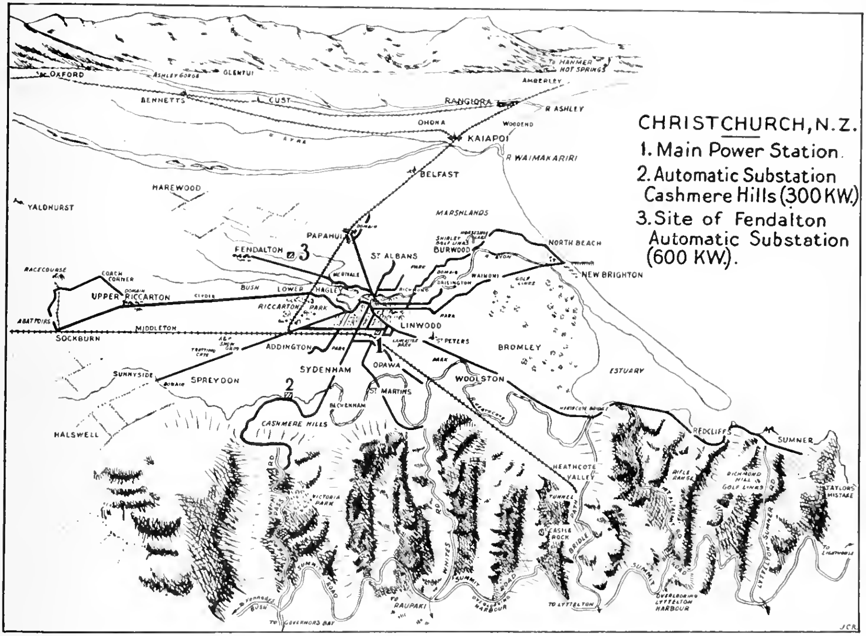


Fig. 1. Layout of Christchurch, N. Z., Tramway Board's Track, Showing Position of Power House and Substation

station of any kind to be installed in New Zealand, and indeed the first full automatic substation in Australasia, very great interest was taken in the work and preliminary trials. Each individual relay and safety device, and

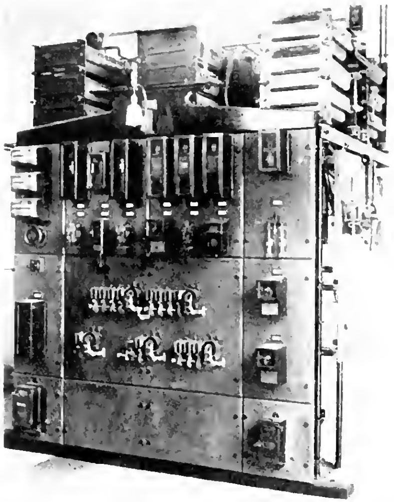


Fig. 2. Automatic Control Panel with Current Limiting Resistors on Top. (Time switch on right-hand bottom sub-base panel)

every section of the control circuits, were tried out and adjusted separately, and not until after all possible combinations of the plant had been tried out in groups was it put on the line as a whole; and it was due mainly to the care taken with these tests that, when first operated as a complete unit on March 11, practically no trouble of any kind developed and two cars were almost immediately sent up the Hill, giving a load of 400 amperes from the substation. After a few minor adjustments of various relays, the substation carried the ordinary service traffic throughout the day, with further minor adjustments during this time. On the following Sunday, March 13, a special trial run was made with four cars, giving a load of 800 amperes, and the current limiting relays adjusted to suit. After these adjustments, the substation was left to take care of itself, and beyond usual routine inspection has since been operating unattended. Views of the station are shown in Figs. 2, 3, and 4.

The cars used on the Hills are all eight-wheel combination cars weighing 18 tons when loaded, and are equipped with two GE-202 motors and K-11 controllers. In addition to the ordinary air and hand brakes on the wheels, these cars are also specially fitted with air-operated track brakes and an additional emergency air reservoir. Actual ammeter readings show an average current of 250 amperes for loaded cars in full parallel on the 9 per cent grade.

One problem of automatic operation not provided for by the manufacturers arose

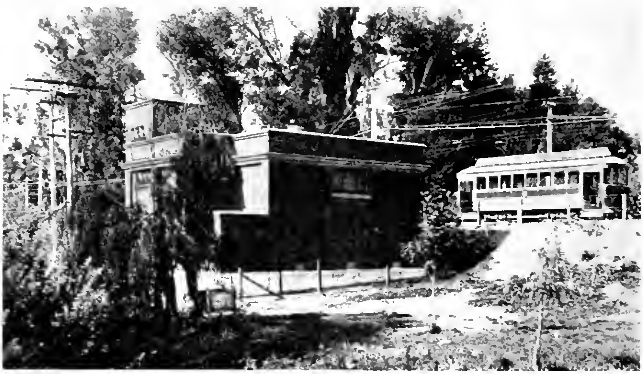


Fig. 3. Exterior Cashmere Hills Automatic Substation, Christchurch, N. Z.

through the tramway service ceasing at midnight. The shutting down of the main Falsgrave Street station at this time of course deadens all trolley lines, and the contact-making voltmeter would cause the Cashmere substation to start up, the Government a-c. line being alive continuously. As no power is required by the tramway system, the time delay stopping relay would eventually shut down the station. As a-c. power is still available, the contact-making voltmeter would again start up the station, and the cycle would be repeated until the starting of the main station at 6 a.m. This difficulty was overcome by installing a time switch in the current control relay circuit, set to open just before the main station shuts down, and closing shortly after the starting of the ordinary day's schedule at 6 a.m.

The whole of the installation was carried out by the Christchurch Tramway Board's staff, assisted by the staff of the local office of the National Electrical & Engineering Company, and under the direction of the Board's engineer.

The installation of the substation has been an unqualified success. It has allowed the recovery of a large amount of feeder copper, and has effected a very appreciable saving in feeder losses, besides providing an increased and more satisfactory car service.

A 600-kw., double unit automatic substation is now on order for the Fendalton district of Christchurch.

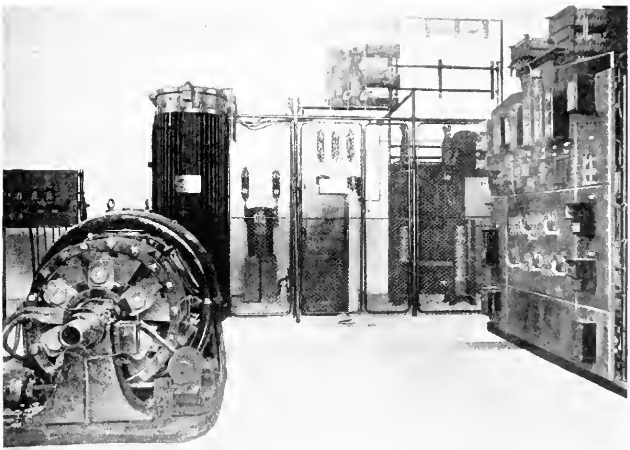


Fig. 4. 300-kw. Synchronous Converter Transformer and Control Gear, Cashmere Hills Substation

Einstein's Theory of Relativity*

By Charles P. Steinmetz

Chief Consulting Engineer, General Electric Company

Einstein's Theory of Relativity has revolutionized science by sweeping aside many of the limitations which hitherto fettered the human intellect. But, being essentially mathematical, a general conception of it can be given to the non-mathematician only by the use of analogies and illustrations, and this inevitably involves a certain looseness of argumentation. The following therefore may serve to give a general idea of the Theory of Relativity, but not to critically review it.—The Author.

Einstein's Theory of Relativity starts from two premises:

1. All phenomena of space, time and motion are relative, that is, there is no absolute motion, etc., but motion, location and time have a meaning only relative to some other location, time, etc.

2. The laws of nature are universal, that is, apply in the same form everywhere, whether in a speeding railway train on earth, or in the empty space between the fixed stars.

So far, these two premises appear simple and rather obvious, but startling and revolutionary ideas appear when carrying the reasoning from these premises to their ultimate conclusions, as Einstein has done.

Suppose for instance, you happen to run your car at 30 miles per hour against a stone wall. There seems nothing relative about this, but the wreck is very real: the stone wall does not budge, and when a rapidly moving mass meets an immovable body, mechanical energy is set free destructively. But is the stone wall really immovable? Is it not, as a part of the earth, spinning around at 800 miles per hour, so that both, the stone wall and your car, were moving? Perhaps if you happened to drive the car in a westward direction, that is, against the rotation of the earth, your car really was moving slower than the stone wall; it was going only 770 miles per hour, and the stone wall 800 miles. But think further: Is not the stone wall, as a part of the earth, revolving around the sun at 70,000 miles per hour? And is not the sun and with it the earth, and the stone wall and your car, also moving on an unknown path amongst the fixed stars? So that really, you know nothing and can know nothing about the actual or absolute speed of the car; all that you know is that the relative speed of the car, that is, the speed relative to the earth and thus also the speed relative to the stone wall, was 30 miles per hour. But that is sufficient to get and understand the effects of the car meeting the stone wall.

So with location. The room in which you are sitting while reading appears fixed and definite. But the only way you can describe its location is by referring it to some other body or location as a reference point, by saying that your room is located x feet north and y feet west and z feet above the surveyor's markstone on city hall square; or you can give its latitude, longitude and altitude, that is, stating that from the starting point of latitude, longitude and altitude (that is, where the equator meets the zero meridian at ocean level), you go so many degrees north (or south), then so many degrees west (or east), and then so many feet up (or down), and thereby reach your room. Three distances thus are required, measured in three chosen directions, from a chosen starting point, to locate a point or an object in space, and therefore we say that space has three dimensions. But do these three distances really locate you in your room? Suppose somebody, reading the directions, would try to locate you one hundred years hence. They would not find you. Thus one more thing must be given: the time, measured from some arbitrary starting point; for instance, anno domini. Thus you see, to locate anything in this world of ours requires four measurements, three distances, and one time, and we thus can say that the world and its events has four dimensions, three dimensions of space and one of time.

But all such location of events in the four dimensional world can only be relative to the arbitrarily chosen reference points in space and time. In bygone ages, when people thought the earth flat and immovable as the center of the universe, we could dream of referring location to an absolute stationary reference point, say the Capitol of Rome. But when the earth became a sphere, spinning around its axis and revolving around the sun, the earth ceased to offer any fixed and permanent reference point in space. The sun then was chosen. But the astronomers found the sun moving amongst the fixed stars.

*A paper read before the Pittsfield Section of the A.I.E.E November 3, 1921.

And the "fixed" stars do not stand still, but are moving every which way, so that all the attempts to find something immovable and fixed in the universe have failed, and thus all motion, all location, can be relative only, to other objects, which are also moving.

Suppose you toss a stone across your room. Observing the point at which the stone leaves your hand, the direction in which it leaves, and the speed, the physicists will calculate the path of the stone, as it curves downwards and finally comes to rest on the floor of the room. Suppose now, you are on a railway train, moving at constant speed on a straight level track, and toss a stone across the car in which you are riding. From the same three observations: the point in the moving railway car where the stone leaves your hand, the direction, and the speed relative to the car, at which the stone leaves, the physicist by the same laws calculates the path which the tossed stone travels in the car, and whether the car is moving at constant speed on straight level track, or standing still, makes no difference; the path of the stone is the same, as the same laws of nature apply everywhere.

If the laws of nature are the same in the railway train moving at constant speed on straight level track, as they are on the "rigid" platform of the earth, or in the empty space amongst the fixed stars, then the speed of light must also be the same, 186,000 miles per second, and so must be the speed with which the electric current travels in its circuit—which is the speed of light. This is important because all observations depend on it: any event is either observed by seeing it, or recorded by some electrical arrangement, and in either case we do not get the exact time when the event occurs, but later by the time it takes the light to reach our eye, or the electric current to flow from the event to the recording device. Due to the enormous speed of the light, this time difference between the moment when the event occurs and the moment when we observe or record it, usually is so extremely small as to be negligible. But not always. For instance, when on shipboard out on the ocean the chronometer has stopped, and the mariner tries to find the location of his ship from the stars, he might use the eclipses of the moons of Jupiter for this purpose. But when he sees the eclipse, it has already passed by from 30 to 50 minutes, depending on the relative position of the earth and Jupiter, due to the time which it takes the light to go from Jupiter to the earth, over the hundreds of millions of miles.

But if the speed of light in a moving train must be the same as on the stationary track, we get some rather strange conclusions. Suppose we place a lamp on the track, back of the receding train, so that the light shines along the track (for instance a signal light). The beam of light travels along the track at 186,000 miles per second. The train moves along the track, in the same direction, at 100 feet per second. Therefore, relative to the train, we should expect the beam of light to travel at 186,000 miles less 100 feet per second. So it would be with a rifle bullet. If I shoot a rifle along the track at the receding train, and the rifle bullet travels along the track at 2000 feet per second, while the train travels in the same direction at 100 feet per second, then the rifle bullet will catch up with the train and pass through the train at the relative speed of 2000 less 100, or 1900 feet per second. But the constancy of the laws of nature teaches us that if the beam of light travels along the track at 186,000 miles per second, and the train in the same direction at 100 feet per second, the speed of the beam of light measured in the train, that is, its relative speed to the moving train, cannot be 186,000 miles less 100 feet as we would expect, but must be 186,000 miles per second, the same as relative to the track. Now the only way we could explain this contradiction is that when we measured the speed of light on the train, our measuring rods were shorter, or, using the length of the train as a measure, the train was shorter, or the time was slower, or both. These three possibilities really are one. It can be shown, if the length of the train is shorter, the time must be slower in the same proportion. Thus this leads to the strange conclusion that when the train is moving, in respect to the beam of light coming from the outside and thus to an outside observer the length of the train has shortened and the time in the train has slowed down. But if we now stop the train and remeasure it, we find the same length, and the same time as before.

This conclusion from the two premises of the theory of relativity is so against our accustomed ideas that we would be inclined to reject it if it could not be verified by experiment, and the experiment has been made repeatedly. It is true, a difference of 100 feet per second, out of 186,000 miles per second, is so extremely small that it could not be measured. But we can speed up the train, instead of 100 feet per second, run it at 100,000 feet, or 20 miles per second. We have such a train: the earth on its path around the sun moves about 20 miles per second. The speed of light going with the motion of the earth then should be 20 miles less, going against the motion of the earth, 20 miles greater. But the experiment shows that it is the same, and that with an accuracy many times greater than the difference in the speed of light, which we should expect but do not find, so that the fact of the constancy of the speed of light is beyond question. Also, then it is beyond question, that motion shortens the length, and slows down the time on the moving body, for an outside observer. Not for an observer moving with the train: for him length and time are the same.

What does this mean? The train stands on the track. I measure it from the outside, you measure it from the inside, and we find the same length. We compare our watches and find them to go alike. Now the train starts and runs at high speed. While it is passing me, I measure its length again, and find it shorter than before, while you traveling with the train measure it again from the inside, and find the same length we both found when the train was standing still. But while passing over it, you measure a piece of the track, and find it shorter than I find it when measuring it from the outside. While you pass me on the train, I compare your watch with mine, and find your watch slower than mine. But you, comparing your watch with mine, while passing me, find my watch slower. Then the train stops, and both our measurements agree again. What then is the "true" length of the train, and the "true" time? That which I get when measuring the train while it passes me at high speed, or that which you get while moving with the train? Both, and neither. It means that length is not a fixed and unvariable property of a body, but depends on the condition under which it is observed. The train has one length to the observer standing still with regard to it, that is, the observer in the train; a different, and a shorter length to the observer, whom it passes at 100 feet per second; and if I could go outside of the earth and measure the length of the train, while the train and earth rush by me at 20 miles per second, I would find a third still shorter length.

Length and time therefore are relative properties of things, depending on the conditions under which they are observed, particularly the relative speed of the body to the observer. This really appears so startling only because it is novel, since at all speeds which we find around us, even the highest speeds of rifle bullets, the change of length and time is so extremely small as to be inappreciable, and we therefore are used to finding length and time constant. Appreciable changes occur only at the speed of 10,000 to 100,000 miles per second and more, while the most accurate methods of measurement would fail to show an appreciable shortening of the railway train going at 60 miles per hour, because the shortening is so small. But it is there just the same.

However, the relativity of the length of a body, that is, the dependence of the length on the condition of observation, is no more strange than the relativity of the color of a body. Off-hand we will say that a body has a fixed and definite color; the grass is green, the snow is white. Nevertheless, when we think of it we know it is not so. The lady buying material for a dress in the dry goods store during the daytime may select a nice heliotrope. But when the dress is finished, in the ballroom she finds its color a clear soft pink. And when, to have a photograph taken, she goes to a photographer using mercury lamps in his studio, she finds the same dress a clear blue. Which is its "true" color? Heliotrope, or pink, or blue? Either is the true color under the condition under which it is observed. So, Einstein's Theory of Relativity proves to us that it is so with length and with time. There is no single length of a body, nor time on the body, but length and time are relative, and vary with the conditions under which they are observed, with the relative speed of the observer, just as the color of a body varies with the kind of light under which it is seen.

If then, in a body moving rapidly past us, the distance appears shortened, and the time slowed down, the speed, which is distance divided by time, must also appear slower. Now the energy of the moving body depends on its mass and its speed, and with the same energy put into the body, if the speed appears slower, the mass must appear larger. We thus draw the conclusion from Einstein's Theory of Relativity, that the mass of a moving body is not constant, but increases with the speed, and the oldest of the great fundamental laws of nature, the law of conservation of matter, thus goes into the discard. For nearly two centuries we have accepted the law of conservation of matter, and believed that matter, that is, mass, can neither be created nor destroyed, and now we find that mass varies with the speed, so that speed, that is, energy, can create mass, and mass or matter probably is merely a manifestation of energy. And this can be, and has been verified experimentally. The decrease of length, the slowing down of time, the increase of mass, becomes appreciable only at velocities approaching those of the light, but at ordinary everyday velocities, length, time and mass are constant. But in the vacuum tubes used in our wireless stations to produce the electrical vibrations which carry the message through space across oceans and continents, the current is carried through the empty space of the tube by minute particles, so-called electrons, and measuring the speed and the mass of these electrons the physicists find that they move at speeds of 10,000 and 100,000 miles per second and that their mass is not constant, but increases with the speed, in the manner as required by Einstein's theory. This was the first experimental proof of the change of mass, and it was found before Einstein gave the explanation in his relativity theory.

Suppose you have a billiard table in your house. You put a ball in the middle of the table. It stays there until something pushes it, and this something we call "force." Or you shoot a ball across the billiard table. It moves in a straight line until it strikes the boundary, rebounds and again moves in a straight line at constant speed. Suppose now we have a billiard table in a train, and the train is running at constant speed on a straight level track. You again put a ball in the middle of the table and it stays there, just as was the case in your house, at rest with regard to the table (though I, standing outside near the track, see that train, and table and ball all three move together, at constant speed). You shoot the ball across the table, and it moves in a straight line at constant speed, thus in the moving railway train obeying the same laws of nature as in your stationary house, namely, that a body keeps the same state, whether at rest or in motion, until something changes its state.

But suppose the train is speeding up, its speed increasing while you put the ball in the middle of the billiard table in the train. Now you find that this ball does not remain at rest, but it begins to move towards the back of the train, first slowly and then more and more rapidly until it comes to rest against the back boundary of the table, just as a stone that I drop does not remain at rest, suspended in the air, but begins to move downward with increasing speed, "falls." So, the billiard ball in the speeding train "falls" towards the back of the train. You shoot a ball across the billiard table, while the train is speeding up; it does not move in a straight line, but curves towards the back of the train, just like a thrown stone on earth does not move in a straight line at constant speed, but curves downward. You say then, that in the speeding railway train some force acts on the billiard ball, pulling it towards the back of the train, just as the attraction of the earth is pulling downwards. You may speculate on this force which attracts things towards the back of the speeding railway train, and find its laws just as Newton found the laws governing the force of gravitation. But I, standing on the embankment, near the track, while the speeding railway train passes, see that there is no real force acting on the billiard ball, but when you put it into the middle of the table, left to itself, it continues to move in a straight line at the speed which it and the train had when you put it there, and what happens is, that billiard table and train, speeding up, slide forward under the ball, and the ball thus seems to fall backwards, towards the end of the train. So when you shoot a ball across the billiard table in the speeding railway train, I from the outside see the ball move in a straight line at constant speed, but see the billiard table and train slide forward under it, so giving you, who are moving with the speeding railway train, the impression of an attracting force pulling the ball towards the back of the train. You try to find the laws of this force, that is, the laws obeyed by the relative motion which you see. But to me these motions are those of a body left to itself, that is, a straight line at constant speed, and knowing the motion of the speeding railway train, the mathematician can calculate the motion which you observe, without any assumption, merely as a mathematical transformation from the straight line motion which I see, to the complicated motion relative to the speeding train which you observe, and so derive the laws of the latter motion, that is, the laws of the fictitious attracting force, to which you ascribe these motions. This Einstein has done, and so derived a new and more general expression for the law of gravitation, in a way which does not depend on any hypothesis on the nature of the force. This law is more general than Newton's law of gravitation and the latter appears as the first approximation of Einstein's law of gravitation.

The more general law of gravitation given by Einstein does not mean that Newton's law of gravitation is wrong; both laws give so nearly the same results in almost all cases, even in the calculation of cosmic motions, that usually the difference cannot be discovered even by the most accurate measurements, that is, Newton's law is a very close approximation of Einstein's. There are a few cases only in the universe as we know it today, where the difference becomes noticeable. Such for instance, is the motion of the planet Mercury. This planet has been observed for thousands of years, but all attempts to accurately calculate its motion by Newton's law have failed while the application of Einstein's law has done so, thus once again corroborating Einstein's Theory of Relativity.

Thus to conclude: the theory of relativity means:

All phenomena of motion, space and time are relative.

The laws of nature, including the speed of light, are the same everywhere.

Herefrom follows, that length, time and mass are relative also, are not fixed properties of things, but vary with the relative speed of the observer.

A more general law of gravitation is derived as a mathematical transformation of straight line inertial motion to the apparent motion relative to a speeding system (the railway train in above illustration) and shows that gravitation is not a real force, but a manifestation of inertia, like centrifugal force.

Types of Lightning Arresters

By J. L. R. Hayden and N. A. Lougee

General Engineering Laboratory, General Electric Company

In our issue of November we published an article on "A Generator for Making Lightning." The present contribution, by the same authors, deals with the different types of arresters in use and explains how the more efficient types not only give better protection against outside disturbances but also cause less disturbance in the circuit itself. The results of testing different types of arresters by the lightning generator are given and much valuable information is incorporated in the oscillograms accompanying the article.—Editor.

The purpose of lightning arresters is to afford protection against surge voltages, which may enter the circuit from such outside agencies as atmospheric disturbances, or those which may originate in the circuit itself. The function of the arrester is to discharge such abnormal voltages—whatever their origin, to ground safely with the least possible disturbance of the normal flow of power in the circuit —preferably without any disturbance at all.

This means that when the lightning discharge to ground occurs, the dynamic current, that is, the normal current produced by the generator in the station and traversing the circuit in transmitting and distributing light and power, must not be allowed to follow the lightning discharge to ground and so short circuit the system, or at least must be interrupted so quickly—within two or three half waves—that the circuit disturbance caused thereby is negligible.

The problem of opening the dynamic following the static thus is one of the most important in lightning arrester design.

Putting a resistance in the discharge path of the arrester, as has often been done, reduces the dynamic current following a discharge and thereby the disturbance caused by it, and makes its interruption much easier. But it also reduces the protective value of the arrester by limiting its discharge rate.

Three types of lightning arresters may be distinguished according to the manner in which the dynamic circuit is interrupted.

Horn Type of Arrester

The horn type allows the dynamic current to flow after the discharge. It consists of two horns, one connected to the line, and the other to ground, and a series resistance. The abnormal voltage jumps the gap between the horns and discharges through the series resistance to ground; the machine current follows; the arc rises between the horns, flares up and opens after some time, clearing the circuit after some seconds, more or less.

The series resistance must be of a sufficient value to prevent a short circuit on the system after the discharge, and to enable the horns to rupture the dynamic current. But the series resistance limits the surge current as well as the dynamic current following the discharge, and is therefore very detrimental from a protective standpoint.

Aluminum and Oxide Film (OF) Arrester

A type of the other extreme is represented by the aluminum cell arrester and the OF arrester, types which pass the abnormal voltage freely with practically unlimited discharge capacity, but which do not allow the dynamic to flow at all. They act towards the normal circuit voltage and the abnormal over-voltage in somewhat the same way as a storage battery, or counter e.m.f. of negligible resistance, would act in the direct current circuit when the battery voltage is equal to the normal voltage of the circuit. No current or practically no current would flow through the battery to ground at normal circuit voltage, but any abnormal voltage, whether over-voltage or high frequency voltage, would discharge freely through the battery. Likewise, no current flows at abnormal circuit voltage through the OF cell or the aluminum cell (except a very small leakage current, and in the aluminum cell a small wattless capacity current); but an abnormal voltage discharges freely with this type of arrester—which by analogy often is referred to as the "Counter E.M.F. Type." A discharge thus produces no disturbance at all in the circuit, and does not appreciably affect the machine voltage and current even for a part of a half wave. It, therefore, is the preferable type of arrester, and is universally used wherever the value of the protective apparatus economically justifies its installation.

Multigap Type of Arrester

However, in primary distribution systems, with thousands of small transformers scattered throughout the circuits, it is not economically feasible to place an aluminum cell or OF arrester at every small transformer, and theory, as well as extended experience, have proven that effective protection of distribution transformers requires the location of a lightning arrester at the transformer. This requires a simple and relatively cheap type of lightning arrester which needs no attention, can be left to itself, and offers the assurance that it will give reasonably good protection; that is, one which reduces the losses by lightning so far that the possible saving by any still further reduction of the losses would not justify the expense of further devices.

The third type of arrester, the multigap, is admirably fulfilling this duty, and has done so for a long time. It is based on the discovery that with a short alternating-current arc between large cold metal terminals the voltage required to start an arc again at the reversal of current is much higher than the voltage required to maintain the arc, and such an arc, therefore, tends to go out at the end of the half wave of current. The multigap lightning arrester in its simplest form thus consists of a number of narrow gaps between brass terminals. The static discharges pass over the gaps from the line to ground. The dynamic or machine current follows and continues until the end of the half wave during which the static has passed, and then goes out if the number of spark gaps is sufficient so that the circuit voltage cannot start the reverse current. The multigap arrester thus short circuits the system for the rest of the half wave during which the lightning discharge occurs; that is, for a fraction of a half wave, or less than 1/120th of a second. While during this short time it pulls the circuit voltage down and takes a large current, the duration is so short that it produces no appreciable disturbance beyond perhaps a momentary flicker of the lights connected from the transformer, and also it does not throw synchronous apparatus out of step, etc.

The essential of the multigap thus is, to have as few gaps as possible to give a low discharge voltage, but to have the number of gaps sufficiently large so that at the reversal of voltage the circuit voltage cannot start a reversal current through the residual arc vapor left in the gap by the preceding half wave of current. The larger the discharge current, therefore, the greater is the liability of the arrester failing to open it at the end of the half wave.

Series resistance, by reducing the discharge current and thus the residual vapor left by it in the spark gaps, increases the interrupting capacity, but is undesirable since it limits the discharge capacity of the arrester.

Shunt resistance, that is, resistance of various values shunting some of the spark gaps, does not lower the discharge capacity of the arrester, and materially assists in opening the dynamic circuit. With shunt resistance, during the half wave in which the lightning discharge occurs, the dynamic follows the static and short circuits, resulting in a large current with no appreciable voltage drop across the arrester. At the end of the half wave, the current stops, but with the large amount of arc vapor left in the gaps, it starts again in the free or series gaps at the beginning of the next half wave. But in the

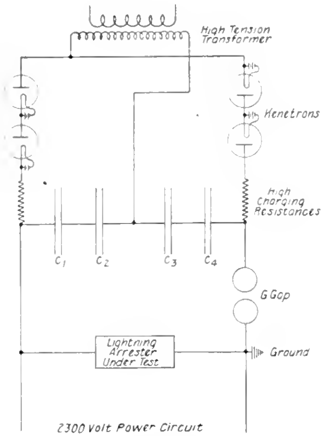


Fig. 1. Circuit Arranged to Impress Impulse from Lightning Generator on a Lightning Arrester When Connected to the Normal Dynamic Circuit

gaps shunted by resistance, especially the lower values of resistance, the current at the beginning of the half wave starts through this resistance which shunts the gaps; that is, there is not enough voltage to start the arc again across the shunted gaps. By passing through the shunting resistance, the current of this second half wave of discharge is materially reduced, and, therefore, when at the end of the second or third half wave it goes out, it will not start again. That is, the dynamic has been put out in two or three half waves—at the end of the first half wave it is shifted to the shunting resistance and the current thus lowered, and at the end of the second or third half wave the circuit is opened. This is well shown by the oscillograms in the following tests which were made with the lightning generator described in the November, 1921, issue of the GENERAL ELECTRIC REVIEW.

* C. P. Steinmetz, GENERAL ELECTRIC REVIEW December, 1920.

TESTS

The circuit is shown in Fig. 1. It represents the discharge from the release of a bound charge on a line. The condensers are gradually charged by the kenotrons, but the arrester is kept at ground potential during this time. This is also the case with an arrester on a transmission line, for on account of leakage through the arrester gaps, low insulation resistance, corona, etc., the transmission line is kept at or near ground potential and a bound charge accumulated on it due to the gradual rise of the charge of the cloud above it.* This bound charge is freed when a lightning flash occurs and the field from ground to cloud collapses. This free charge then has a very high potential against ground and discharges through the arrester. Likewise, in the test circuit, when the sphere gap, G, discharges, it grounds and discharges that side of the condenser to which it connects, and thereby sets free the charge on the other side of the condenser, which up to then was bound, that is, at ground potential. This freed charge instantly rises to the full potential above ground, and causes a discharge through the lightning arrester.

Fig. 2 shows the action of a 2300-volt multigap arrester consisting of series gaps, and a number of gaps shunted by a resistance of about 30 ohms. An arrester typical of this type is shown in Fig. 4. The impulse dis-

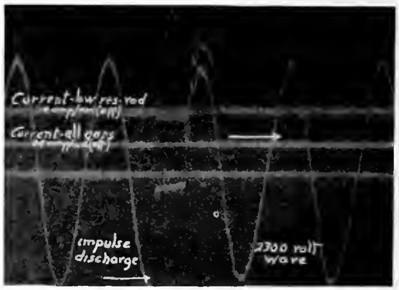


Fig. 2. Action of a 2300-volt Multi-gap Arrester During Impulse Discharge

charged through all the gaps, as this path is the one of lowest resistance, and has a great current discharge capacity. The dynamic 60-cycle current followed the impulse across the gaps for one-half cycle, and was then shunted to the low parallel resistance rod.

Thus during the second half wave, the current passed over only the series gaps and the low resistance rod, and was so limited that it was extinguished by the series gaps at the end of the second half cycle. The 2300-volt supply used was a regular city distribution circuit and attention is particularly called to the effect that the arrester has on the voltage of this circuit. This shows that there is a momentary short circuit on a system for one-half cycle every time such an arrester discharges a heavy impulse, and a consequent dropping of the voltage to zero. During the second half cycle of the discharge, the voltage has again largely recovered, due to the shunt resistance limiting the current, but still shows some effect. It is normal again in the next half wave.

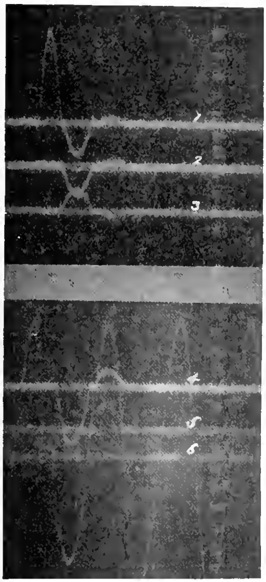


Fig. 3. A 2300-volt Multi-gap Arrester During Impulse Discharge. Special type to show action of shunt resistances

This phenomenon of shunting the dynamic arc from the gaps to a resistance is brought out in an interesting manner by the oscillogram in Fig. 3. In this combination of series gaps and shunted gaps, the resistance of the shunted gaps was graded. That is, each gap had a particular value of resistance shunting it, starting with a low value across the first gap, a little higher across the next, etc. In Fig. 3, vibrator 1 gives current through the arrester, vibrators 2, 3, 4 and 5 give

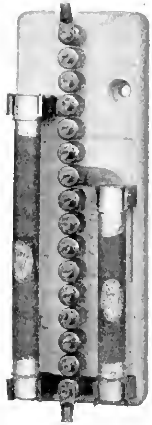


Fig. 4. Type GE Form F2 Single-pole Station Arrester for 2300-volt Circuit

voltage across the first four shunt gaps respectively, and vibrator 6 gives line voltage across the arrester. It will be noticed that after the impulse passed the dynamic went through all the gaps directly and caused a momentary short circuit on the line as indicated by the line voltage. During the second half cycle, the first three low resistances were shunted in as shown by the high voltage across these gaps by vibrators 2, 3 and 4 in the oscillogram—if the dynamic current goes through the gap only, the voltage drop is very low, and gives no indication on the oscillogram. These three low resistances lowered the dynamic current about one-half, but not sufficiently to have it extinguished at the end of the half cycle. During the third half cycle, however, the highest resistances were cut in, as shown in the oscillogram by vibrator 5 across one of them, and the current was greatly reduced and extinguished at the end of this half cycle.

A less efficient arrester than these multigap types with shunted gaps would cause this heavy dynamic current to flow for more than one-half cycle; for instance, one of the plain horn gap types would cause a circuit disturbance for many cycles or possibly for many seconds and thus cause synchronous apparatus to go out of step. A horn arrester, even with the necessary series resistance to

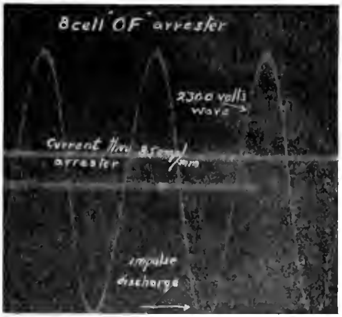


Fig. 5. Action of a 2300-volt "OF" Arrester During Impulse Discharge

prevent failure, must depend upon extinguishing the dynamic arc by lengthening it as it travels up the horns, and this is a comparatively slow process. A multigap arrester, however, by the shunting phenomenon, decreases the dynamic current to a value where the series gaps can extinguish it, in one, two, or sometimes three half cycles. All discharges are not heavy enough to necessitate the low resistance path through all the gaps, and hence, light discharges will pass through the series gaps and low resistance to ground. In such cases, a momentary short circuit is not caused, for the dynamic current is limited by the resistance and extinguished at the end of the first or second half cycle.

Fig. 5 shows a 2300-volt, 8-cell, OF arrester under the same conditions. A three-phase arrester of this type is shown in Fig. 6. The contrast between the action of a gap or horn type arrester and an OF arrester is striking. Here the impulse can be seen occurring at the peak of the 2300-volt wave and discharging through the arrester. But there is no dynamic current following the discharge and there is absolutely no disturbance to the

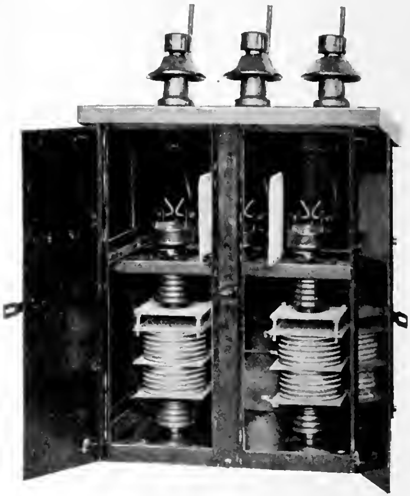


Fig. 6. Type "OF" Form "BO" Oxide Film Lightning Arrester for Outdoor Service on Three-phase Circuits, 1000/3000-volts

2300-volt circuit. That is, the punctured films are sealed up so quickly after the impulse passes, by the reduction of the lead peroxide (PbO_2) filler to litharge (PbO) or red lead (Pb_3O_4), that no visible disturbance is noted.

Factory Illumination and Production

By G. H. Stickney and H. E. Mahan
Edison Lamp Works — Illuminating Engineering Laboratory
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The subject dealt with in this article is of great importance always, but of more particular importance during this period of reconstruction, when it is necessary to get the maximum production from machines already installed. There must be numerous factories throughout the country that could increase production to a marked extent by better illumination. However well the factory may have been lighted according to the practice in vogue four or five years ago, there is likely to be a possibility of securing profitable increase of production by adopting the latest methods and more recent reflector equipment. An actual operating test is, of course, the surest way of determining if such economy can be effected. This is illustrated by the present instance, where the former lighting was considerably better than is even now usual for such processes.—Editor.

Progressive manufacturers have been convinced that increased production and better workmanship justify raising the standards of artificial lighting in their factories far above the levels of ordinary practice.

At first thought it would seem to be a very simple matter to measure the increase in production due to such higher standards. Nevertheless, for well understood reasons, it has been found exceedingly difficult to secure reliable data of this sort.

Taking advantage of a special condition, tests were run in Chicago which have provided the most notable data of this sort yet available. These tests were described by Mr. W. A. Durgin of the Commonwealth Edison Company, in the *Transactions of the Illuminating Engineering Society*, Volume 13 (1918), page 417, also in the *Electrical Review*, March 22, 1919.

Some of the engineers of the General Electric Company have been desirous of securing such data in connection with the lighting of the Company's shops both for the information of the manufacturing organization and of the Company's customers.

On investigation, it was found particularly difficult to locate workrooms suitable for the purpose. The Company's shops were already well illuminated both by daylight and by artificial light; and further, the nature of most processes was such as to prevent an accurate segregation of artificially lighted production from that under daylight. However, a test was run on a small scale at the Schenectady Works during the past year under the supervision of the Company's Illuminating Engineers and Cost Accountants. The results of this test are herewith presented as an indication of what may be expected under more or less similar conditions.

The section in which the tests were made is devoted to semi-automatic buffing. These machines consist of a revolving turret upon which spindles are provided for supporting punchings which are moved past buffing wheels. The operator controls the pressure of these buffing wheels against the punchings by observing the degree of polish on the stampings as they move by an opening in front of him. The material handled is a uniform product and the operations are completely standardized so that the fundamental essentials for a test of this nature are fulfilled. The data refer exclusively to night operations under artificial light and with the same operators. It is, therefore, obvious that the variables likely to vitiate the results have been reduced to a minimum and that the results may be accepted as reasonably conclusive.

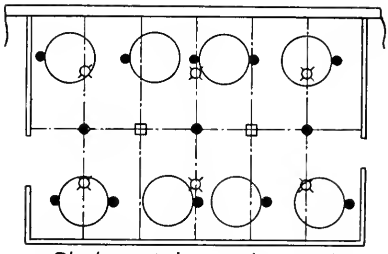

Fig. 1. Diagram Showing Arrangement of Machinery, Position of Outlets and Location of Photometric Reading Stations

The arrangement of machinery and the position of the outlets are indicated in Fig. 1, and during the period of ordinary intensity lighting these outlets were equipped with 300-watt clear Mazda lamps and bowl type porcelain enamel steel reflectors. During the period of the high intensity lighting these same outlets were equipped with 500-watt bowl enameled lamps and the RLM standard reflector. The lighting units were suspended approximately 14 feet above the floor. The power requirements were increased from 1.2 watts per square foot of floor area to 2.01 watts which resulted in the illumination being increased from 3.8 foot-candles to 11.1 foot-candles. Careful records of production were made for a period of five months, during three months of which the ordinary intensity lighting was in operation, and during the remaining two months the high intensity lighting. The records of production for the two months' period, during which operations were carried on under the high intensity lighting, showed an average increase of 8.5 per cent over the average production during the preceding three months' period of moderate intensity lighting.

A complete analysis of this question must, of course, include consideration of its economic features in order to decide whether or not the procedure as a whole is advantageous. The following computations have been made to show the relatively small cost the lighting bears to the labor cost and to the value of the increased production. These figures establish an incontrovertible argument in favor of liberal illumination provisions.

	Moderate Intensity Per Cent	High Intensity Per Cent
Cost of lighting* in per cent cost of labor	0.86	1.86
Cost of lighting in per cent factory cost of products	0.033	0.066
Average increase in production attributed to high intensity lighting		8.5
Increase in cost of lighting to increased value of production.		0.4

* Cost of lighting includes cost of power at $0.015 per kw-hr., cost of lamps, 15 per cent depreciation on reflector equipment and 6 per cent on investment.

There is a great deal of investigating to be done along the lines suggested in this article. A valuable increase in output has been secured on a small scale in a process which would not ordinarily be considered as likely to be largely benefited by so-called productive lighting. Nevertheless, there is no indication that even this high standard represents the most profitable level for this operation.

Furthermore, other processes will have different economical levels, depending on such variables as the demand on vision, value of product, need of increased production, cost of labor, cost of material, cost of overhead, importance of accuracy. Needless to say, it is not practical to segregate all these variables, but as we accumulate more and more such figures representing various typical processes, they will serve as a guide to better practice.

With the foot-candle meter now available the intensity levels and variations can be more readily analyzed and interpreted with regard to the effect of illumination on production.

It must also be recognized that a large majority of processes are so operated that it is not practicable to measure the increase in production due to more and better lighting. The lack of such measurement, however, does not indicate the absence of profitable gains. In fact, it is probable that the percentage of increased work per hour will be greatest in the less automatic and less organized processes.

In conclusion, the writers desire to emphasize the importance of these questions which warrant investigation by any factory management. In interpreting such results, the value of the unmeasurable features, such as improved morale and better workmanship, should not be overlooked.

The Mechanism of the Surface Phenomena of Flotation

By Irving Langmuir
Research Laboratory, General Electric Company

To assist in propounding a satisfactory theory for the flotation processes of ore separation, Dr. Langmuir advances a theory of adsorption and surface tension and describes some simple experiments that have been conducted to show the applicability of the theory. Considerable knowledge of the phenomenon of adsorption was acquired from research work in high vacua and this knowledge formed the foundation of the hypothesis respecting the formation and action of thin oil films on the particles of ore in the flotation process. The demand for copies of this paper, which was originally read before the Faraday Society in 1919, is responsible for its publication in the General Electric Review at this time.—Editor.

Notwithstanding the importance which the flotation process has assumed in the separation of ores, there has been comparatively little progress in the development of the underlying theory. It is recognized that the process depends on the formation of thin oil films on the particles of ore and that owing to the difficulty with which these particles are then wet by water they become readily attached to the air bubbles and are thus carried to the surface. As far as I know, however, no really satisfactory theory of these phenomena has been proposed. The remarkably selective action of some oils on certain ores and the effects produced by small amounts of acids and other substances are very imperfectly understood.

The object of this paper is not to offer a new theory of flotation, but rather to call attention to a theory of adsorption and surface tension which greatly aids in understanding these phenomena and which therefore should prove useful in developing any comprehensive theory of flotation. Some simple experiments will be described showing that the new viewpoint is applicable to flotation processes.

The surface phenomena of flotation may be divided roughly into three classes: the formation and properties of the froth; the oiling of the solid particles; and the adhesion of the oiled particles to the bubbles of the froth. The formation of the froth depends on the existence of a film of oil or other substance at the boundary between the air and water phases. The oiling of the solid particles involves the formation of a similar film at the surface of the solid. The adhesion of the particles to the bubbles depends primarily on the ease with which oily water wets the oily solid and this in turn is measured by the angle of contact between these oiled liquid and solid surfaces. The formation of the oil films on the surfaces of the water and the solid particles is a typical case of adsorption so that an understanding of the fundamental phenomena of flotation requires a knowledge of the nature of adsorption.

For several years I have been engaged in a study of high vacuum phenomena, especially the effects produced when various metals are heated in gases at very low pressures. In some cases the rate of disappearance (or clean-up) of the gas was measured, while on others the electron emission from the heated metal was observed. In the course of this work it was frequently found that adsorbed films of extraordinary stability were formed on the surface of the metal. The evidence from a large number of such experiments indicated clearly that these stable films consisted of a single layer of atoms chemically combined to the underlying atoms of the solid. The adsorbed atoms were chemically saturated but the atoms in the surface of the metal were not saturated by their combination with the adsorbed atoms and therefore remained firmly held by the next underlying layer of metal atoms. This viewpoint was based to a large extent on the work of the Braggs on crystal structure.

The atoms in the very stable films referred to are clearly held to the surface by direct chemical union of the primary valence type, like that holding oxygen to carbon in carbon dioxide. Further investigation showed that in some other cases of adsorption such as that of nitrogen or argon by charcoal, etc., the forces involved, although no less chemical than the others, were of the type represented by secondary valence such as that holding water of crystallization, or ammonia in complex ammonia derivatives.

A further extension of this theory led to the view that no fundamental distinctions should be drawn between the so-called physical phenomena and those recognized as chemical. Thus condensation of vapors, crystallization, surface tension, adsorption, etc., are manifestations of forces of the same kind such as those involved in the formation of chemical compounds.*

From this viewpoint, the forces involved in the adsorption of organic substances with large molecules do not originate from the molecule as a whole, but rather from certain atoms in the molecule. The theory indicates that adsorbed films in general should be one molecule in thickness. Lord Rayleigh in 1899 (Phil. Mag. *48*, 331, 1899) observed that a film of olive oil just thick enough to lower appreciably the surface tension of water had a thickness of 1.0×10^{-7} cm. He stated: "Now this is only a moderate multiple of the supposed diameter of a gaseous molecule, and perhaps scarcely exceeds at all the diameter to be attributed to a molecule of oil. It is obvious, therefore, that the present phenomena lie entirely outside the scope of a theory such as Laplace's, in which matter is regarded as continuous, and that an explanation requires a direct consideration of molecules.

"If we begin by supposing the number of molecules of oil upon a water surface to be small enough, not only will every molecule be able to approach the water as closely as it desires, but any repulsion between molecules will have exhausted itself. Under these conditions there is nothing to oppose the contraction of the surface—the tension is the same as that of pure water."

If the molecules "behave like smooth rigid spheres of gaseous theory, no forces will be called into play until they are closely packed. According to this view the tension would remain constant up to the point where a double layer commences to form. The actual course of the curve of tension deviates somewhat widely from the above description, but perhaps not more than could be explained by heterogeneity of the oil whereby some molecules would mount more easily than others, or by reference to the molecular motions which cannot be entirely ignored. If we accept this view as substantially true we conclude that the first drop in tension corresponds to a complete layer one molecule thick, and that the diameter of the molecule of oil is about 1.0×10^{-7} cm."

By a similar method Devaux (Ann. Report Smithsonian Inst., Washington, 1913, 261) concludes that the diameter of the molecule of triolein is 11.3×10^{-8} cm. if the molecule be assumed spherical in shape.

According to the present theory, however, molecules should not be regarded as spheres since such a supposition is not consistent with the chemical nature of the forces. The spreading of an oil on the surface of water is therefore due to an attraction between the water and some active group in the oil molecule. If the molecule as a whole had an affinity for water it would render it soluble in water. It is known that the presence of $-COOH$, $=CO$ or $-OH$ groups in an organic molecule increases the solubility in water while the hydrocarbon chain decreases it. On the other hand, hydrocarbons are soluble in each other. When an oil containing the carboxyl group is placed on water these active groups combine with the water, while the hydrocarbon chains remain combined with each other by secondary valence forces. On an unlimited surface the oil thus spreads until all the $-COOH$ groups have come into contact with the water, forming a monomolecular film. A pure paraffin oil, since it contains no active groups, does not spread on water.

By measuring the greatest area of water that can be completely covered by a small weighed amount of oil it is possible to determine the cross sections and lengths of the molecules. The thickness of the oil film gives the length of the molecule measured vertically while the area covered by each molecule gives its cross section. Results obtained this way show that the molecules in oil films are not even approximately spherical. This is shown by the data of Table I.

Thus the molecules of the fatty acids from palmitic to cerotic are all of the same cross section, but their length increases in proportion to the length of the hydrocarbon chain. Tristearine has a cross section three times that of stearic acid, but the length of the molecule is the same. The areas covered by the oils or fats are thus proportional to the number of active groups present. The molecule of cetyl palmitate is nearly ten times as long as it is wide ($\sqrt{\overline{a}}$,) while the molecule of triricinolein (castor oil) has a length only about one third of its width. The results show that these differences of shape are strictly in accordance with the theory of the chemical nature of the phenomena.†

* The evidence for these conclusions is given in the following papers by the writer: Chemical Reactions at Low Pressures, *Jour. Amer. Chem. Soc.*, *37*, 1139 (1915); The Constitution and Fundamental Properties of Solids, *Jour. Amer. Chem. Soc.*, *38*, 2221 (1916); and the Adsorption of Gases on Plane Surfaces of Glass, Mica, and Platinum, *Jour. Amer. Chem. Soc.*, *40*, 1361 (1918). A review of this work is given by Wm. C. McC. Lewis in his recent System of Physical Chemistry, Longmans, Green & Co., 1918, Vol. 1, pages 461-474.

† The experimental and theoretical work underlying the above statements has been published in the following papers by the writer: Surface Tension Phenomena, *Met. Chem Eng.*, *15*, 468 (1916); The Shapes of Group Molecules Forming the Surfaces of Liquids, *Proc. Nat Acad. Sciences*, *3*, 251 (1917); The Constitution and Fundamental Properties of Liquids, *Jour Amer. Chem. Soc.*, *39*, 1848 (1917). A short summary of some of this work has been given by Wm. C. McC. Lewis, *Physical Chemistry*, Vol. 1, p. 474.

The same theory has been applied to surface tension phenomena in general. According to this theory the molecules of organic liquids arrange themselves in the surface layer in such a way that their active portions are drawn inwards, leaving the least active portion of the molecule to form the surface. Surface tension is a measure of the potential energy of the stray field extending out from the surface layer of atoms. The molecules in the surface layer arrange themselves so that this potential energy is a minimum. The surface energy of a liquid is thus not a property of the molecule as a whole, but depends only on the *least active portions of the molecules* and on the manner in which these are able to arrange themselves in the surface layer.

that of the hydrocarbons. This is partly due to the fact that the large volume of the NO_2 or I forces the CH_3 groups apart and increases the surface energy. This theory was tested by the writer for a large number of organic substances for which data were available. Particularly strong support for the theory was found in the case of benzine derivatives. A few months after the publication of the writer's preliminary results, W. D. Harkins, who had independently arrived at somewhat similar views, published two papers† dealing in great detail with the surface tension at the interface of two liquids and with surface tensions of pure liquids. The data prove conclusively the general validity of the theory given, which is practically identical with that previously advanced by the writer.

TABLE I

CROSS SECTION *a*, AND LENGTH *l* OF MOLECULES

Substance	Cross Section a	$\sqrt{a}$	Length l
Palmitic acid $C_{15}H_{31}COOH$	22×10^{-16}	4.7×10^{-8}	21.4×10^{-8}
Stearic acid $C_{17}H_{35}COOH$	22	4.7	23.8
Arachidic acid $C_{19}H_{39}COOH$	22	4.7	25.9
Cerotic acid $C_{25}H_{51}COOH$	22	4.7	33.0
Cetyl alcohol $C_{16}H_{33}OH$	21	4.6	21.9
Tristearine $(C_{18}H_{35}O_2)_3C_3H_5$	69	8.3	23.7
Cetyl palmitate $C_{15}H_{31}COOC_{16}H_{33}$	21	4.6	44.0
Oleic acid $C_{17}H_{33}COOH$	48	6.9	10.8
Erucic acid $C_{21}H_{41}COOH$	44	6.6	14.2
Triolein $(C_{18}H_{33}O_2)_3C_3H_5$	145	12.0	11.2
Linoleic acid $C_{17}H_{31}COOH$	47	6.9	10.7
Linolenic acid $C_{17}H_{29}COOH$	70	8.4	7.1
Ricinoleic acid $C_{17}H_{32}(OH)COOH$	100	10.0	5.2
Castor oil $[C_{17}H_{32}(OH)COO]_3C_3H_5$	290	17.0	5.5

In liquid hydrocarbons of the paraffin series the methyl groups at the ends of the hydrocarbon chains form the surface layer. The surface is thus the same no matter how long the chain may be. As a matter of fact, the surface energy* of all the hydrocarbons from hexane to molten paraffin is substantially constant, namely 46 to 50 ergs per sq. cm., although the molecular weights differ very greatly.

If now we consider the alcohols CH_3OH, C_2H_5OH, etc., we find that their surface energies are practically identical with those of the hydrocarbons. The reason is that the surface layer in both cases consists of CH_3 groups. With such substances as CH_3NO_2, CH_3I the surface energy is much greater than

* The total surface energy γ_0 is related to the surface tension γ by the equation $\gamma_0 = \gamma - T\,(d\gamma/dT)$ where T is the absolute temperature.

† W. D. Harkins, *Jour. Amer. Chem. Soc.*, *39*, 354, 541 (1917).

In his first paper Harkins gives the values of the change of free surface energy when one sq. cm. of interface is formed between two liquids. A few of these data are shown in Table II in the column headed $(-\Delta\gamma)$. In every case one of the two liquids forming the interface is water.

In the column headed γ is the free surface energy of the non-aqueous liquid against air, while the last column, γ_0, gives the total surface energy $\gamma - T\,(d\gamma/dT)$. It is readily seen both from these data and from theoretical considerations that $-\Delta\gamma$ is a measure of the activity of the *most active portion* of the molecule, while γ_0 is a measure of the activity of the *least active* part of the molecule. Thus in the surface of a substance like octyl alcohol the hydroxyl groups are drawn in towards the interior of the liquid and thus contribute little towards the surface energy γ_0. But octyl alcohol is placed in contact with water the molecules forming the interface are oriented so that the hydroxyl groups come in contact with the water. The free surface energy γ is only very approximately a measure of the strength of the least active portion of the molecule. The size of the molecule determines the amount of thermal agitation and influences the value of γ, whereas γ_0 is usually independent of temperature and depends only slightly on the size of the molecule.

It is apparent that considerations of this kind must be of fundamental importance in connection with the theory of the flotation process. Before much progress in this direction can be made, however, it is necessary to develop experimental methods for the investigation of oil films on solid bodies. With this end in view I have undertaken some simple experiments along these lines.

TABLE II

CHANGE OF FREE ENERGY IN FORMATION OF AN INTERFACE WITH WATER

Liquid	Temp.	$-\Delta\gamma$	γ	γ_0
Water (against water)	20 deg.	145.6	72.8	110.0
Hexane C_6H_{14}	25 deg.	41.2	18.7	49.5
Octane C_8H_{18}	20 deg.	46.0	21.8	48.4
Paraffin oil	17 deg.	47.8	31.8	54.2
Octylane C_8H_{16}	17 deg.	72.9	22.3	....
Octyl alcohol $C_8H_{17}OH$	20 deg.	91.8	27.5	50.8
Ethyl ether $(C_2H_5)_2O$	20 deg.	79.2	17.1	48.4
Caprylic acid $C_7H_{15}COOH$	18 deg.	93.7	28.8	....
Oleic acid	20 deg.	89.0	32.3	....
Ricinoleic acid	16 deg.	94.9	35.8	....
Ethyl nonylate	20 deg.	77.0	28.0	....
Castor oil	17 deg.	87.7	37.1	....
Benzine	20 deg.	66.2	29.0	70
Benzyl alcohol	22 deg.	107.4	39.7	39.7

EXPERIMENTAL PART

A study was first made of the properties of cleaned and oiled glass surfaces. It was especially desired to find how much oil must be present on a glass surface to materially alter its properties.

Microscope slides were washed with soap and water, were heated in a mixture of concentrated sulphuric acid and chromic oxide, and were finally washed in running tap water and dried over a Bunsen burner flame. During this whole treatment they were held in a pair of forceps. This method of cleaning proved to be much more thorough than any other method tried.

When a drop of clean water is placed on a slide cleaned in this way the water wets the glass readily, and when the slide is inclined the surplus water runs to one end, leaving a thin film of water over the whole surface of the glass. Another indication of the cleanliness of the surface is obtained by dipping the slide into a clean surface of water on to which a small amount of talc powder has been dusted. The talc particles are not repelled from the glass surface if it is clean, but very small amounts of grease can be detected by the motion of the talc particles produced by the spreading of an oil film on the surface of the water. This test for the cleanliness of a surface will be referred to as the talc test.

Another characteristic of a thoroughly cleaned glass surface is the extraordinary friction observed when the glass is rubbed with another clean piece of glass or platinum. Lord Rayleigh* has recently called attention to this fact and pointed out its significance in connection with the theory of lubrication. It is also interesting to note that Faraday in his Experimental Researches (paragraph 369) mentions the "peculiar friction" observed when a platinum rod was rubbed over a surface of a platinum plate which had been thoroughly cleaned by making it cathode in electrolysis or by heating it in concentrated sulphuric acid.

In order to study this effect quantitatively some small glass sliders ranging from 0.2 to 1.0 gram in weight were made by bending glass rods in the form of a horseshoe and well rounding the ends. The two arms of the horseshoe were then arched in a plane per-

* Phil. Mag., 35, 157 (1918).

pendicular to the original plane of the horseshoe so that when the slider was laid on a flat surface it touched in three definite points. If one of these sliders was placed on a clean slide it was found that the slide could be tilted usually to an angle of 70 deg. from the horizontal, often 75 deg., and in some cases 90 deg. or even 92 deg. before it would begin to slide. Of course, before beginning this test it is essential to clean the slider by the method already given. If the slider was forced over the surface of the slide a squeaking noise was always heard if the glass was clean and the surface of the glass was scratched perceptibly in the process. It was found that much more consistent results were obtained if when the glass was tilted the slider was pushed over the surface by means of a pair of forceps. The angle was measured at which the slider would just stop moving after being set in motion by the forceps. The sliding angle thus found varied between 50 deg. and 60 deg. for different samples of glass cleaned by the method described. On standing in the air for a short time the surface becomes slightly contaminated, so that the sliding angle decreases. Thus after three minutes the angle is 45 deg., after 20 minutes 40 deg., after two hours 22 deg. This contamination is also shown by the talc test. The actual size of the slider used seemed to be without effect on the results.

If a small amount of oleic acid or other oily substance is placed upon a clean glass slide and this is then thoroughly wiped with a clean cloth, it is found that the sliding angle decreases to a value ranging from about 6 deg. to 10 deg. The talc test can be tried repeatedly with such a surface and each time the slide is moved up or down in the water a fresh contaminated area is produced. By holding an oiled slide under running water in such a way that the water continually advances and recedes from the oily surface the surplus oil may ultimately be removed so that no contamination is indicated by this talc test. The sliding angle, however, remains small. The friction test is thus much more sensitive than the talc test.

If pure paraffin oil is placed on a clean slide the oil readily wets the glass very much as water does, whereas oleic acid draws together on the glass in globules. The paraffin oil lowers the sliding angle nearly as effectively as oleic acid, but the behavior of such a surface towards water is radically different. Thus if a clean slide covered with paraffin oil be held under a very gentle stream of water the paraffin detaches itself from the glass in large drops and the glass becomes wet by the water. If the slide is then dried at low temperature it is found that the sliding angle is 40 deg. or more, showing that all paraffin oil has been removed from the glass.

In order to put a monomolecular film of oil on a glass surface the following method was adopted: The surface of water in a long narrow tray was cleaned by scraping with a strip of paper extending across the tray. A very small quantity of oleic acid was placed on the water at one end of the tray and the spreading of the film was made visible by traces of talc powder. By adding the oil in very small portions the surface was finally saturated with oil without leaving any globules of oleic acid except at the end of the tray at which they had been added. Previous work had shown that an oleic acid film formed in this way has a thickness of 22×10^{-8} cm. and consists of a single layer of molecules each occupying an area of about 24×10^{-16} sq. cm., the spacing thus being the same as that of stearic acid and the other saturated fatty acids. The cleaned slide was then dipped edgewise into the water covered by this film and slowly withdrawn. As the slide was raised it remained at first wetted by the water and the film of oil spread itself over the newly formed water surface. The motion of small particles of talc showed that the oil film moved upward at the same rate as the slide was raised, so that there was no concentration of oil on to the surface of the glass. When a clean slide is originally dipped into the water the talc particles close to the surface do not move either towards or away from the slide. This indicates that no oil goes on to the glass surface while this is being lowered into the water. This remarkable fact is confirmed by removing the oil film from the surface of the water by scraping and blowing before withdrawing the slide from the water. If the slide is then dried at ordinary temperature it is found both by the talc test and the friction test that the surface is still entirely free from oil. If on the other hand the slide has been raised from the surface saturated with oil and is held in a vertical position the water film gradually moves down and the oil film on it comes into contact with the glass. The same result may also be obtained by holding the slide in a horizontal position and allowing the water to evaporate. In this way the glass surface is covered with a film of oil of the same thickness as that originally present on the surface of the water.

A slide treated in this way appears just as clean as before, but if dipped in clean water it is found that the water no longer adheres to it but gradually runs off, as from a greasy surface. The talc test gives a rather slight indication of contamination, but if the slide is raised and lowered repeatedly in pure water, or is passed several times through a gentle stream of running water, it soon loses its ability to contaminate water. The friction test gives a sliding angle of about 6 deg. to 10 deg., whether or not the surface has been washed by clean water before drying.

In other experiments the film of oleic acid was allowed to expand on the water surface until the surface tension was nearly that of pure water. The thickness of such a film (see Table I) is 11×10^{-8} cm., and the area covered per molecule is 48×10^{-16} sq. cm. A glass slide oiled by dipping and slowly withdrawing from this oiled water and drying in a horizontal position gave sliding angles ranging from 6 deg. to 20 deg. The results were rather erratic and indicated that the oil was not uniformly distributed over the slide, but was concentrated somewhat on those portions which were the last to dry. If the slide was allowed to dry in a vertical position, the upper part of the slide was found entirely free from oil, while the rest of the slide was uniformly covered.

Mica

Freshly split mica (biotite) is very readily wetted by water and by paraffin oil, but oleic acid and molten stearic acid form globules. These acids, however, leave the surface greasy even after the globules have been removed. Paraffin oil behaves as it does on glass, that is, a gentle stream of water displaces it completely from the surface. Dipping the clean mica into a water surface saturated with oleic acid does not contaminate the mica, but withdrawing it and allowing the water to evaporate gives an oiled surface. This differs, however, markedly from an oiled surface of glass. The oil is given up in larger quantities in the talc test, and after the surface has been repeatedly passed through a stream of water, it becomes wetted nearly as easily as a surface of freshly split mica.

A glass or platinum slider gives a sliding angle of about 10 deg. on clean mica and about 6 deg. on mica which has been dipped in water and saturated with oleic acid. The slipperiness of clean mica as compared with clean glass (sliding angle 60 deg.) is very striking.

Platinum

A smooth piece of platinum foil (1½ by 3 inches) was polished with sea sand and ignited to a red heat. It was readily wet by water. As in the case of glass and mica, platinum does not become contaminated when dipped into oiled water, but only when it is drawn out and dried. Clean platinum gives a sliding angle of 35 deg. with a platinum slider, and 30 deg. with a glass slider. After dipping once in water saturated with oleic acid and drying, the sliding angle with both glass and platinum sliders was 14 deg. By a second dipping the angle fell to 6 deg. with the glass and 12 deg. with the platinum slider. The surface after single dipping loses very little, but after double dipping loses a considerable quantity of oil in the talc test. The loss of this oil does not increase the sliding angle. It seems that only the oil which is not in true contact with the platinum is lost during the talc test. Repeated passing through a stream of water does not increase the sliding angle or the tendency of water to gather into globules on the oiled platinum surface.

Paraffin oil behaved the same on platinum surfaces as on those of glass.

Calcite, Sphalerite, Galena, Pyrites and Magnetite

Fresh cleavage surfaces or fractures of these minerals were all readily wetted by water or paraffin oil, and in each case the paraffin oil was readily displaceable by water. The clean surfaces all became greasy by dipping into water saturated by oleic acid, and in every case it was impossible to remove the greasiness by repeatedly passing through a stream of water. On cleavage surfaces of calcite and galena rough qualitative observations showed that there was a peculiar friction, as in the case of glass.

Measurement of Contact Angles of Drops of Water on Oiled Surfaces

Simple observation showed that drops of water behaved rather differently on various solid surfaces which had been dipped into water saturated by oleic acid.

Drops of water placed on oiled glass flattened out to a layer about 2 mm. thick. By tilting the glass the drop would advance over the surface at the lower edge, forming a rather large angle of contact, while at the rear edge the water would recede from the glass rather slowly, and the angle of contact was much less than at the advancing edge. The moving drop was usually rather irregular in outline. On mica the depth of the drop is less than on glass, and the drops are more irregular in shape after moving over the surface. With platinum the drops of water become thicker and more symmetrical in shape, while on galena they show a still greater thickness and regularity.

To obtain more definite information, drops of water ranging from 0.7 to about 1.22 cc. in volume were placed on oiled surfaces and their heights measured by a vernier attached to a fine point brought into contact with the drop and subsequently with the solid surface on which the drop had rested. The results are given in Table III. The figures in the columns marked h represent the depths of the drops in millimeters, while θ is the average contact angle as calculated from the equation

(1) $$h = a\sqrt{2}\,sin\,(\tfrac{1}{2}\theta)$$

where a is given by

(2) $$a = \sqrt{2S/(g\rho)}$$

case a very small amount of talc was dusted on to the drop after measuring it, and by gently blowing on it the contaminated surface was forced to one side where its area could be estimated. The areas were always less than about 60 or 70 per cent of the whole surface, so that the surface tension of the drop could not have been appreciably affected. This conclusion was checked in some cases by repeating the measurements after the surface had been washed by passing through a stream of running water until drops placed on the surface were no longer contaminated. In each case (except mica) the results remained unaltered. In calculating the angles of contact, S in equation (2) was placed equal to 72.8, so that equation (1) became (3)

$$h = 0.546\,sin\,(\tfrac{1}{2}\theta)$$

The measurements given in column II of Table III were made after the drops of water

TABLE III

HEIGHT AND CONTACT ANGLES OF WATER DROPS ON SURFACES COVERED BY MONOMOLECULAR FILMS OF OLEIC ACID

Solid	I. CLEAN WATER		II. WATER SATURATED WITH OLEIC ACID	
	h	θ	h	θ
	mm.			
Mica	0.9	18 deg.	0.9	24 deg.
Quartz	....	....	1.2 ±	31 deg. ±
Glass	2.1	45 deg.	1.5	42 deg.
Platinum	2.9	65 deg.	2.45	72 deg.
Calcite	3.1	70 deg.	2.75	82 deg.
Sphalerite	3.6	82 deg.	3.0	92 deg.
Galena	3.7	86 deg.	3.35	106 deg.

Here S is the surface tension; g the acceleration of gravity, and ρ the density of water. This equation is accurate only for large drops Those actually used ranged from 1.4 to 2.5 cm. in diameter, and a further increase in the size of the drop did not appreciably alter the value of h.

In each case the oily surface was prepared by dipping a thoroughly cleaned (or cleavage) surface into water saturated with oleic acid, and drying at low temperature. The water drop was then placed on the surface and this was shaken and sometimes tilted slightly, so that the drop reached a stable shape. The results given are the averages of several observations. In most cases the individual observations on different drops agreed within about 0.1 mm. in the value of h.

The measurements of the column marked *I* were made with drops of clean water. In many cases the drops were slightly contaminated by oil from the solid surface. In every

had been touched by a wire dipped in oleic acid. In this case S of equation (2) was taken to be 42.8, so that the coefficient of equation (3) was 0.418 instead of 0.546.

A few measurements of water drops were made on surfaces of paraffin, stearic acid, cetyl alcohol, myricyl alcohol and cetyl palmitate (spermaceti). These were prepared by spreading the molten fat or wax over a glass slide while cooling. All these substances except paraffin tend to draw up into globules on the glass; cetyl alcohol does this particularly strongly. To get a uniform coating it was necessary to "iron out" the wax by a heated glass rod.

On solid paraffin the height (h) of the drop was 4.4 mm. (2.5 mm. after adding oleic acid). The contact angle of the pure water was thus 110 deg. The drop in this case tends to slide over the glass with the utmost ease—a drop weighing 0.8 gram slides when the inclination of the surface is only about 2 deg.

With stearic acid h was 3.9 mm., but this could only be realized after prolonged washing of the surface to prevent contamination of the drop. The drops of water are much less mobile than on paraffin, thus a drop of 0.8 gram does not slide over the surface until the inclination is 6 deg. to 8 deg.

Myricyl alcohol gave $h=4.1$ and gave results resembling those on paraffin. Cetyl palmitate also resembled paraffin. Cetyl alcohol on the other hand became wetted (or nearly so) by the water, but the water had become completely covered by a film. Even very prolonged washing of the cetyl alcohol did not prevent this contamination of the surface of water drops. These results are cited only to show how remarkably specific the properties of these various substances are.

DISCUSSION OF EXPERIMENTAL RESULTS

The experiments have shown clearly that oil films of molecular thickness are sufficient to alter radically the surfaces of solids. This is shown not only by the lubricating properties of these films but also by the contact angles made by water drops.

The properties of these monomolecular films as measured by their contact angles depend apparently as much on the character of the underlying solid as upon the nature of the oil. Thus the minerals galena and sphalerite give much larger contact angles when contaminated by oleic acid than those obtained with glass or quartz under similar conditions. This result seems to be inconsistent with the theory of surface tension discussed in the early part of this paper according to which the surface tension depends only on the nature of an arrangement of the atoms forming the actual surface. From this viewpoint we would be led to believe that the upper surface of oil films on solid bodies should in every case consist of CH_2 or CH_3 groups, and thus the properties of all the films should be similar. However, there is an important distinction between the case of an oil film covered by a water drop and the surface layer of a pure organic liquid. The water drop on the film tends to draw the active groups to itself. In the case of oleic acid there are two active groups in the molecule, namely, the carboxyl and the double bond. It is probable that in some cases both of these are rather firmly held by the underlying solid, while in others only the carboxyl group is so held and the double bond is free to come in contact with water. Thus on galena we may assume that both active groups are held by the solid so that the water has only a little more tendency to spread on the oiled surface than on solid paraffin. With glass, on the other hand, some of the active groups may be brought to the upper surface by contact with water so that the water spreads much more easily than over paraffin. This theory readily explains the marked difference between the contact angle of an advancing and receding surface on glass contaminated by oleic acid.

Another factor which must be taken into account is that the spacing of the molecules in oil films on solids must be determined primarily by the surface lattice of the solid, whereas with films on liquids the molecules are able to arrange themselves largely without reference to the underlying liquid. As a result the films on solids are ordinarily not in stable equilibrium; many molecules are crowded into spaces too small for them, while others may occupy unnecessarily large areas. As a matter of fact in all the experimental work with films on the solids the results were much more irregular and depended much more on slight differences in the previous history of the film than was the case with films on liquids.

To test this theory more fully it will be desirable to repeat experiments of the type described above with many different kinds of oils and fatty substances.

The explanation of the ease with which paraffin oil wets solid surfaces and yet is easily displaced by water is probably as follows: We may assume that the attractive force between hydrocarbon molecules and the solid surface is greater than that between hydrocarbon molecules, but active groups like those contained in water or oleic acid are attracted to the solid surface very much more than are hydrocarbon molecules. The paraffin oil thus readily wets the solid if brought into contact with it, but the hydrocarbon molecules are readily displaced from the surface layer when either water or oleic acid is present. When oleic acid is forced over the surface of glass a monomolecular layer of this substance covers the glass. The acid draws into globules on this surface, however, because by so doing the active groups can come into contact with each other (probably forming clusters), whereas if they remained spread out on the surface they could only come into contact with the less active portions of the molecules forming the surface film. It is evident that this tendency to gather into globules does not occur with pure paraffin oil.

The fact that clean solid surfaces do not become contaminated when dipped into a water surface saturated with oleic acid is readily explained by the fact that the active groups of the surface film are in contact with the water and are thus turned away from the solid surface while this is being pushed down into the water. On drawing it out, however, the active groups of the surface film are on the side nearest to the solid surface.

The peculiar property of mica in giving such a small sliding angle even when cleaned indicates that the surface is covered with water molecules with their hydrogen atoms thoroughly saturated and turned outwards to form the surface layer. The great ease with which mica cleaves and the readiness with which oil films can be washed off and water can spread on these oil films is also a result of the small residual field of force extending out from these surface hydrogen atoms.

APPLICATION OF THE THEORY OF FLOTATION

Formation of Froth

The formation of froth depends on the presence of substances which can form a stable monomolecular film over the surface of each bubble. In order that froth may readily form it seems to be desirable to have present a soluble substance having a strong tendency to be adsorbed on the surface of the liquid. For example, a small amount of acetic acid added to water produces a rather unstable froth. As we go to the higher fatty acids, for example, valeric acid, the tendency to form a froth is much increased. On the other hand, oleic acid does not readily produce a froth unless it is rendered soluble in water, as for example, by forming soap by the addition of sodium hydroxide. Oil of pine tar, so often used as a frothing agent, contains soluble substances that probably act in this way. The presence of alkalies in flotation is to be avoided probably because the hydroxyl ion tends to draw the carboxyl group of the fatty acid to itself rather than to allow it to attach itself to the solid particles.

Oiling of the Solid

The particular properties of different kinds of oils for this purpose must be made the subject of further careful study. The presence of small amounts of acid and substances which become adsorbed on the solid surfaces or attach themselves to the oil films would be expected to alter the results materially. This subject is, of course, a very large one, and will necessitate much experimental work before it becomes well understood.

Contact Angle of Solid Particles

The tendency of the particles to attach themselves to the bubbles of the froth is measured by the contact angle formed between the oily surface of the bubble and the contaminated surface of the solid. For the case where oleic acid forms both films the data given in column II of Table III are applicable. The results indicate that the selective action by which substances like galena are separated from quartz and calcite is dependent upon the contact angle formed by the oiled surfaces rather than by any selective tendency for the oil to be taken up by some minerals more than by others.

The object of this paper has been to show the applicability of a rather new viewpoint and particularly to stimulate further research into the mechanism of the flotation process. I am much indebted to Miss Katharine Blodgett for carrying out most of the experimental work.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Air Conditioning

Air Filtration Technically Considered.
Elec'n (Lond.), Sept. 30, 1921; v. 87, pp. 410-412.
(Results of tests by an English firm on air filters used in connection with the cooling system of 15,000-kw. turbo-alternators.)

Alternators

New A.C. Generator with Asymmetric Voltage Characteristic. Breslauer, Max. (In German.)
Elek. Zeit., Sept. 15, 1921; v. 42, pp. 1025-1029.
(Describes and illustrates a new alternator producing asymmetric current for use in x-ray and electrochemical applications.)

Armature Windings

Laminated, Transposed Armature Bars. Punga, Franklin and Roos, Hermann. (In German.)
Elek. und Masch., Oct. 2, 1921; v. 39, pp. 485-489.
(Illustrated paper on theory and methods of construction of the B.B.C., A.E.G., and other schemes. Serial.)

Cars, Electric

Urban Transportation Field Analyzed. Thirlwall, J. C.
Elec. Rwy. Jour., Oct. 1, 1921; v. 58, pp. 546-550.
(G-E engineer presents an analysis of operating costs of the safety car, the trolley bus and the motor bus.)

Condensers, Steam

Relative Efficiency of Various Types of Condensing Apparatus. Brewer, Allen F. and Stivers, Frank A.
Mech. Engng., Oct., 1921; v. 43, pp. 672-673.
(Shows test results.)

Electric Conductors

Copper-Wire Properties and Requirements Governing Installation. Slack, Edgar P.
Power, Oct. 18, 1921; v. 54, pp. 590-591.
(Includes useful tables of data on standardized stranding for copper wire and on properties and installation requirements of copper wires and metal conduits.)

Electric Current Rectifiers

Advances in the Construction of Mercury Vapor Rectifiers. Höpp, W. (In German.)
Elek. Zeit., Sept. 15, 1921; v. 42, pp. 1032-1036.
(Brief review of recent progress, methods of neutralizing back-arcing, simplification of low-capacity rectifiers, etc.)

Steel-Clad Rectifier Merits Attention. Milliken, J. H.
Elec. Wld., Oct. 29, 1921; v. 78, pp. 863-865.
(An illustrated discussion of large-capacity mercury vapor rectifiers of the BBC type.)

Electric Drive—Marine Auxiliaries

Electric Auxiliaries on Merchant Ships. Dickinson, E. D.
A.I.E.E. Jour., Oct., 1921; v. 40, pp. 777-785.
(G-E engineer discusses various applications of electric drive for ship auxiliaries.)

Electric Drive—Mining

Coal Mine Power Transmission. Adams, W. C.
W. Soc. Engrs. Jour., Oct., 1921; v. 26, pp. 337-349.
(On the general principles of electric power distribution in coal mines.)

Demand Factor of Coal Mining Loads. Lee, Carl.
W. Soc. Engrs. Jour., Oct., 1921; v. 26, pp. 350-359.

Electric Drive—Steel Mills

Economical Generation of Electrical Power. Clark, A. B.
Assoc. Ir. & St. Elec. Engrs., Oct., 1921; v. 3, pp. 479-491.
(Pertains to power generation in steel mill work.)

Electric Furnaces

Superheating Iron Electrically. Elliott, George K.
Iron Tr. Rev., Oct. 20, 1921; v. 69, pp. 1007-1011.
(Describes a special use of the electric furnace in foundry melting.)

Electric Locomotives

Characteristics of the Electric Locomotive. Storer, N. W.
Frank. Inst. Jour., Oct., 1921; v. 192, pp. 453-468.

Some Mechanical Characteristics of High-Speed, High-Power Locomotives. Gibbs, A. W.
Frank. Inst. Jour., Oct., 1921; v. 192, pp. 469-495.
(Concerned principally with electric locomotives.)

Electric Meters

Mechanical Frequency-Meter of Telephonic Range. Kennelly, A. E. and Manneback, Ch.
Frank. Inst. Jour., Sept., 1921; v. 192, pp. 349-359.
(Illustrated description.)

Electric Motors, Induction

Induction Motor Nomogram. A Movable Diagram for Reading All Performance Characteristics of Any Three-Phase Induction Motor. Warner, R. G.
A.I.E.E., Jour., Oct., 1921; v. 40, pp. 808-814.

Electric Motors, Railroad
Some Mechanical Causes of Flashing on Railway Motors. Stotz, J. K.
Elec. Jour., Oct., 1921; v. 18, pp. 481-482.

Electromagnets
Practical Method for Calculating Operating Characteristics of Magnet Coils. Underhill, Charles R.
Elec. Wld., Oct. 29, 1921; v. 78, pp. 872-875.
(Methods of estimating current-time relations and distribution of energy.)

Factory Lighting
Better Illumination Cuts Production Costs. Harrison, Ward and others.
Elec. Wld., Oct. 15, 1921; v. 78, pp. 763-764.
(Actual test data to show increase in production due to improved factory lighting.)

Gears, Reduction
Speed-Reduction Gearing for Ship Propulsion. Love, Robert.
Inst. Engrs. & Shipbuilders, Trans., Sept., 1921; v. 64, pp. 63-89.

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Requirements in the Design of Steam Power Stations for Hydraulic Relay. Powell, E. B.
Mech. Engng., Oct., 1921; v. 43, pp. 650-652, 674.
(Discusses the selection of proper steam-driven equipment to compensate for variations in available water power.)

Inductive Interference
Inductive Interference as Seen by the A. R. A.
Elec. Wld., Oct. 15, 1921; v. 78, pp. 767-769.
(Causes and effects of inductive interference. Part of a report submitted by the inductive interference committee of the American Railway Association.)

Power
Electricity Direct from Coal. Polakov, Walter N.
Ind. Man., Oct., 1921; v. 62, pp. 220-222.
(Describes a proposed scheme for producing electric energy direct from coal through the medium of a galvanic element called a "fuel-chain.")

Radio Communication
Digest of United States Patents Relating to Radio Telegraphy and Telephony Issued June 21, 1921–August 16, 1921. Brady, John B.
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Railroads—Electrification
Freight Service on Electric Railways. Stoffel, T. H.
Elec. Jour., Oct., 1921; v. 18, pp. 474-476.
(Short article on general principles involved on electric locomotive lines.)

Reactors
Application of Reactances to Large Systems. Coates, W. A.
Beama, Oct., 1921; v. 9, pp. 330-334.

Statistics—Fuels
Analysis of Industrial Power. Goodwin, Jr. H.
Power, Oct. 18, 1921; v. 54, pp. 584-588.
(Includes extensive tabulated and graphic statistics on industrial power equipment and on fuel consumed in the Superpower Zone.)

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Various Determinations of the Specific Heat of Steam and Their Technical Significance Schmolke, H.
Mech. Engng., Oct., 1921; v. 43 pp. 675-677.
(Mathematical article translated from Zeit fur Dampfkessel und Maschinenbetrieb.)

Steam Plants
Past and Future Development in Power Plants Hirshfeld, C. F
Elec. Rev. (Chgo.), Oct. 1, 1921; v. 79, pp. 509-515.
(Paper before Cleveland Section of A. S. M. E. Analyzes the steam power plant situation.)

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Features of Electric Tool Steel Practice. Green, W. J. and Green, S. Stuart.
Iron Age, Oct. 27, 1921; v. 108, pp. 1061-1064.
(A general discussion of the manufacture of electric furnace tool steel.)

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Steam Superheaters: Their Design, Construction, Application and Use. Oatley, H. B.
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The Negatron. Scott-Taggart, John.
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(Abstract of paper before the British Association. Illustrates and explains the principles of a new negative resistance vacuum tube for radio work.)

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The Kaplan Turbine: Its Construction and Application. Reindl, C. (In German.)
Zeit. des Ver. Deut. Ing., Oct. 1, 1921; v. 65, pp. 1035-1040.
(Treats of the development, advantages and possible applications. Presents test results showing its behavior under various operating conditions. Serial.)

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Speed Regulation of Hydraulic Turbines—I. Carpenter, John S.
Power Pl. Engng., Oct. 1, 1921; v. 25, pp. 947-950.
(Theory and practical examples. Serial.

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Electrical Rates. Watkins, G. P. 228 pp., 1921, N. Y., D. Van Nostrand Company.

Electricity in Steel Works. McFarlane, Wm. 109 pp., 1921, N. Y., Sir Isaac Pitman & Sons. Pitman's technical primers.)

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Power Factor Correction. Clayton, A. E. 108 pp., 1921, N. Y., Sir Isaac Pitman & Sons. (Pitman's technical primers.)

Testing of Continuous Current Machines. Smith, Charles F. 102 pp., 1921, N. Y., Sir Isaac Pitman & Sons. (Pitman's technical primers.)

Wiring for Light and Power. Ed 3. Croft, Terrell 1921, N. Y., McGraw-Hill Book Company, Inc.

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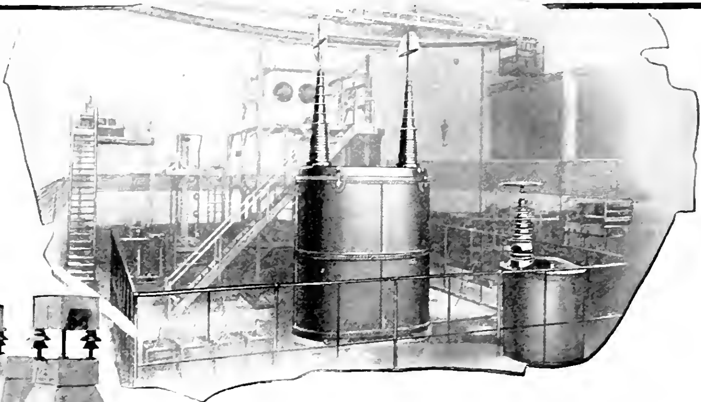

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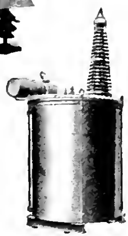

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